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Enhancement of Sulphur Capture in Circulating Fluidized Bed Combustion

121 pp

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ENHANCEMENT OF SULPHUR CAPTURE IN CIRCULATING FLUIDIZED BED COMBUSTION

Final Report
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SUMMARY

This is the final report on the enhancement of sulphur capture in circulating fluidized bed combustors.

A number of alternatives for the enhancement of sulphur capture were examined. These were injection of reactivated (hydrated) bed material, use of hydrated lime, combustor humidification and cool side humidification.

The results indicate that bed material (waste) can be reactivated through hydration to produce a sorbent which is more reactive than fresh limestone. The sulphur capture using hydrated bed material at a Ca/S ratio of 2:1 was 83% compared to 72% for limestone.

The use of hydrated lime led to a significant improvement in sulphur capture. However the improvement was not sufficiently large to make the use of hydrated lime economically viable.

Combustor humidification led to a sulphur capture in the order of 78% compared to 72% for the base run. Based on this modest increase in sulphur capture, this alternative would probably have a low priority in future evaluations.

The results on cool side humidification were not conclusive because of severe caking problems around the water spray nozzle in the humidification chamber. There are, however, some indications that substantial improvement in sulphur capture may be possible.

RÉSUMÉ

Il s'agit du rapport final sur l'amélioration de la capture du soufre dans le mode de combustion en lit fluidisé.

Un certain nombre d'options pour l'amélioration de la capture du soufre ont été examinées. Celles-ci sont l'injection du matériau du lit réactivé (hydraté), l'utilisation de la chaux hydratée, l'humidification à haute température et l'humidification à basse température.

Les résultats indiquent que le matériau du lit (déchets) peut être réactivé par l'hydratation afin de produire un sorbant qui est plus réactif que la chaux fraîche. La capture du soufre à l'aide du matériau du lit hydraté à un ratio de Ca/S de 2:1 était de 83 % comparativement à 72 % pour la chaux.

L'utilisation de la chaux hydratée a amélioré considérablement la capture du soufre. Toutefois, l'amélioration n'a pas été suffisante pour rendre l'utilisation de la chaux hydratée économiquement viable.

L'humidification à haute température a donné une capture du soufre de 78 % comparativement à 72 % pour la méthode ordinaire. Selon cette augmentation modeste de la capture du soufre, cette option aurait probablement une faible priorité dans les évaluations ultérieures.

Les résultats de l'humidification à basse température n'ont pas été concluants en raison des graves problèmes d'agglomération des cristaux autour du gicleur d'eau dans la chambre d'humidification. Certains indices cependant laissent prévoir qu'une amélioration substantielle de la capture du soufre est possible.

TABLE CONTENTS

SUMMARY ..... (i)

RÉSUMÉ ..... (ii)

TABLE OF CONTENTS ..... (iii)

LIST OF FIGURES ..... (iv)

LIST OF TABLES ..... (v)

1.0 INTRODUCTION 1

2.0 TEST FACILITY 3

3.0 START-UP, TEST AND MANAGEMENT PROCEDURES 7

4.0 RESULTS AND DISCUSSION 11

4.1 Feedstock Characteristics 11

4.2 Operating Conditions and Test Results 14

4.3 Operating Experience 22

4.4 Sulphur Capture 28

5.0 CONCLUSIONS AND RECOMMENDATIONS 35

5.1 Conclusions 35

5.2 Recommendation for Future Work 36

6.0 REFERENCES 37

APPENDIX A: Statement of Work

APPENDIX B: Raw Data, Chemical Analyses and Mass Balances

APPENDIX C: Bed Material Hot and Cold Hydration Results

APPENDIX D: Spray Nozzle Specification

LIST OF FIGURES

		PAGE
Figure 1.	Schematic of RPC Circulating Fluidized Bed Combustor Showing Temperature, Absolute Pressure and Flow Sensors	4
Figure 2.	Schematic of RPC Circulating Fluidized Bed Combustor Showing Solid and Gas Sampling Locations	8
Figure 3.	Determination of the Solids Recirculation Rate	10
Figure 4.	Average Chemical Composition for Selected Solid Samples	18
Figure 5.	Schematic of the Cooling Section Showing Location of the Spray Nozzle and Thermocouples	26
Figure 6.	Cooling Section Temperature Profile	27
Figure 7.	Photographs showing cake build-up on the Spray Nozzle and on the Sides of the Cooling System	29
Figure 8.	Sulphur Dioxide Concentration with and without Water Spray	30
Figure 9.	Degree of Sulphur Capture for Tests 1 through 7	32

LIST OF TABLES

		PAGE
Table 1.	Chemical and Particle Size Analysis of Minto Coal	12
Table 2.	Chemical and Particle Size Analysis of Havelock Limestone and Havelock Hydrated Lime	13
Table 3.	Test Matrix for the Assessment of Alternatives for the Enhancement of Sulphur Capture	15
Table 4.	Operating Conditions, Measured and Calculated Parameters	16
Table 5.	Average Chemical Composition of Selected Solid Samples	17
Table 6.	Chemical Composition and Particle Size Analysis of Bed Material and Hydrated Bed Material	20
Table 7.	Nozzle Selection	24

1.0 INTRODUCTION

The Research and Productivity Council was contacted by DSS - Contract No. 23440-9-9189/01-SQ - in response to a request from CANMET to evaluate alternatives for the enhancement of sulphur capture in Circulating Fluidized Bed Combustors. The project was co-funded internally through an ACOA/RPC program.

Circulating fluidized bed combustion is recognized as a versatile and practical technology for clean combustion of high sulphur coals and other problem (high sulphur, high ash) fuels. One of the crucial factors in determining the economics of the process is the overall Ca/S ratio i.e. the limestone requirement for a given level of sulphur capture.

Recent results from N.B. Power's demonstration unit in Chatham showed that the Ca/S ratio required for 90% sulphur capture could be as high as 3:1. This is much higher than the original estimate of 1.25:1 for 90% sulphur capture. Hence, a need for new approaches for the enhancement of sulphur capture was identified. Process options to be considered include precalcination and hydration of limestones, use of more reactive sorbents, additives such as NaCl and Fe_2O_3, waste activation and recycling, humidification, sorbent slurry injection or a combination thereof.

Among the alternatives mentioned above, humidification and sorbent slurry injection have been demonstrated successfully, on the pilot scale and demonstration levels, in conjunction with in-furnace injection of calcium based sorbents, for sulphur capture from conventional pulverized coal fired power plants. These techniques, however, have not as yet, received sufficient attention with regard to their applicability to circulating fluidized bed combustion systems.

In this study a preliminary assessment of the applicability of humidification and waste activation to circulating fluidized bed combustors was carried out. The effectiveness of hydrated lime was also evaluated.

This report describes test work carried out including test procedure, test condition and results. Conclusions regarding the effectiveness of the sulphur capture enhancement techniques under consideration are also given together with recommendations for future work.

2.0 TEST FACILITY

The test work was carried out with minimum modification to RPC's existing test facility which is shown schematically in Figure 1. The main components of the system are the combustor, a primary cyclone and a standpipe for solid circulation, a flue gas cooling section, secondary cyclone and a baghouse.

The Combustor

The cylindrical combustor has a total height of 5.8 m (19') and inside and outside diameters of 12.7 cm (5") and 50.8 cm (20") respectively. The wall has an inner layer of high temperature refractory, a middle layer of castable insulating refractory, and a carbon steel shell. A 0.5 MBtu propane burner is used for start-up purposes.

Primary air is fed into the bottom of the combustor via a distributor plate; a perforated plate with 10% open area located 66 cm (26") from the base of the combustor column. Secondary air is fed into the combustor via four diagonal ports at 205.7 cm (81") above the distributor plate.

Stand Pipe

The standpipe is used for storage and recirculation of solids received from the primary cyclone. It is 0.9 m high and has inside and outside diameters of 22.8 cm (9") and 62 cm (24") respectively. The standpipe is refractory lined and is equipped with discharge and sampling ports.

A cooling section is installed at the bottom of the standpipe. This is used to extract excess heat generated in the combustor so that both bed temperature and air/fuel ratio can be set and maintained at the appropriate levels.

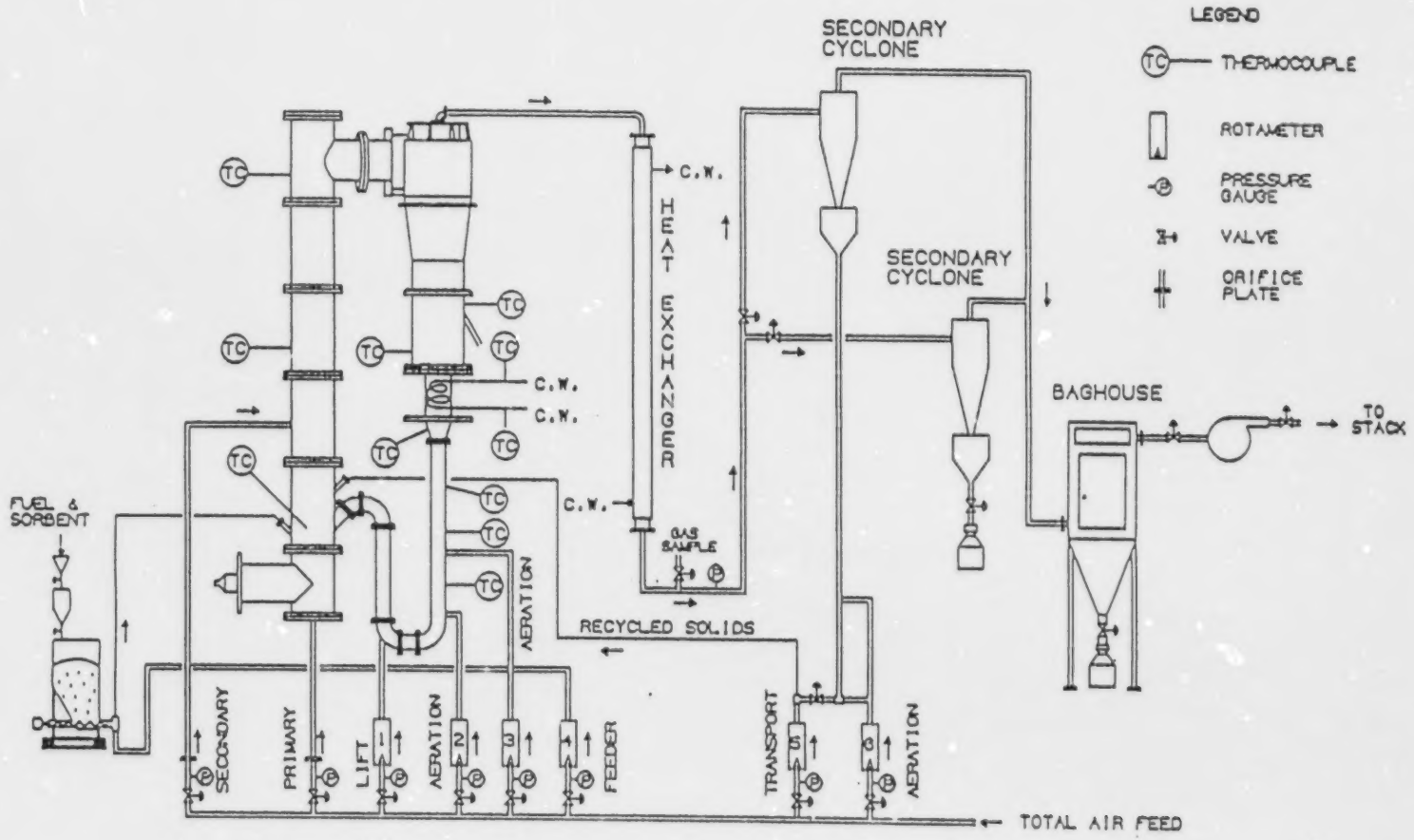


FIGURE 1

SCHEMATIC OF RPC CIRCULATING FLUIDIZED BED COMBUSTOR SHOWING TEMPERATURE, ABSOLUTE PRESSURE AND FLOW SENSORS

Cyclones

The primary cyclone is 30 cm (12") in diameter and is refractory lined in a similar manner to the combustor and the standpipe. The two identical secondary cyclones are made of stainless steel and are 25 cm (10") in diameter. The solids collected by the secondary cyclone can be recycled pneumatically to the combustor via a port, 48.3 cm (19") above the distributor plate.

The J-Valve

Circulation of solids from the standpipe to the combustor is achieved by a non-mechanical J-valve. The vertical section is made of 3" Schedule 40 stainless steel pipe. It is aerated at two points approximately 0.21 and 1.06 m from the base of the J-valve. The curved section is made of 2" schedule 40 stainless steel pipe. Lift air is supplied at the base in order to transport the solids into the combustor entering at a location 0.37 m above the distributor plate.

Gas Cooling System

Off-gases from the primary cyclone are fed into a water cooled one pass heat exchanger. It is made of two concentric pipes of a nominal diameter of 15 cm (6") (Schedule 40) and 20 cm (8") (Schedule 40), respectively. The height of the heat exchanger is 5.2 m (17').

The Baghouse

The flue gases from the cooling section are fed through the secondary cyclone into the baghouse. The latter is a continuous duty self-cleaning dust collector which consists of 16 high temperature bags capable of handling 200 SCFM.

Solid Feeding

Dry solids are fed pneumatically into the combustor 44.5 cm (17.5") above the distributor plate. The feed rate is regulated using a screw feeder. The feeder assembly is mounted on a weighing scale to provide an accurate record of the feed rate.

3.0 START-UP, TEST AND MANAGEMENT PROCEDURES

The system is preheated using a 0.5 MBtu/hr propane burner, which is normally fired at half its rating. Once the combustor temperature reaches 200-300°C, the bed material is introduced into the system. For this particular test program ash from previous tests was used as the starting bed material. Coal feed is initiated and the propane burner switched off at a bed temperature of approximately 600°C. At a bed temperature of approximately 850°C, the cooling section at the bottom of the standpipe is activated and the operating conditions are set for a particular test run.

Tests were carried out sequentially whenever possible, with a transition period between tests of 2 to 6 hours. Gas composition (particularly SO_2 concentration) and bed temperature are the two main indicators used to signal the end of the transition period. For each test the experimental measurements and analysis consisted of the following:

Solids Flow Rates

(a) Feed, Standpipe Overflow, Baghouse Dust

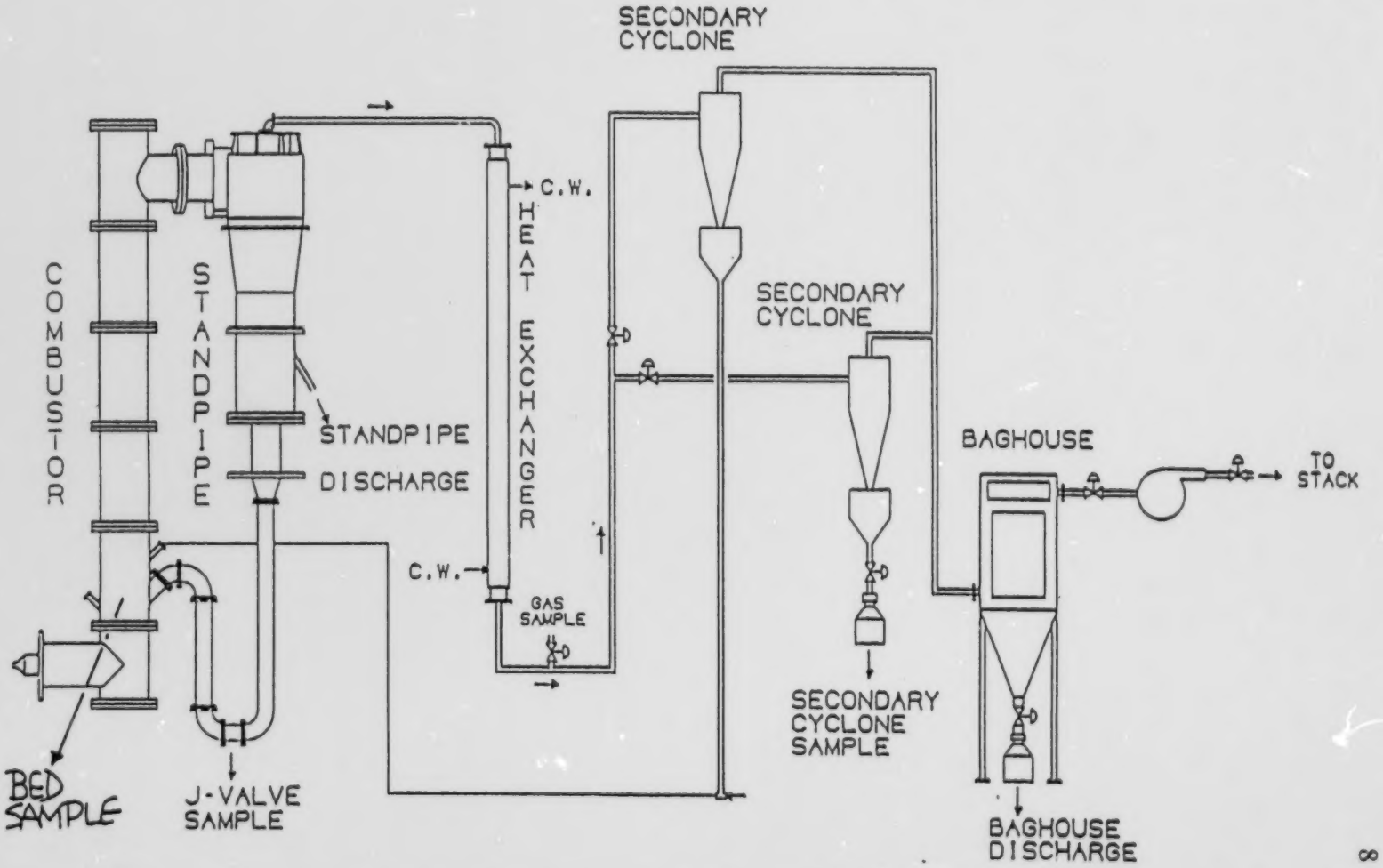
These measurements were taken every hour.

(b) Secondary Cyclone Recycle

This measurement was taken every four hours in order to minimize the disruption to the circuit. To take this measurement, the stand-by secondary cyclone (see Figure 2) was brought on-line and the underflow was collected for a given period of time (typically 5 min).

FIGURE 2

SCHEMATIC OF RPC CIRCULATING FLUIDIZED BED COMBUSTOR SHOWING SOLID AND GAS SAMPLING LOCATIONS



(c) Solids Recycle Rate Through Standpipe

The recycle rate is calculated every hour by carrying out a simple heat balance calculation as illustrated in Figure 3.

Air Flow Rate

Primary air and secondary air flows to the combustor are recorded every hour. Also recorded at hourly intervals were lift and aeration air to the J-valve, feeder air and transport and aeration air for the secondary cyclone recycle were recorded at hourly intervals.

Temperatures

Temperatures were recorded hourly at several locations in the combustor and the standpipe.

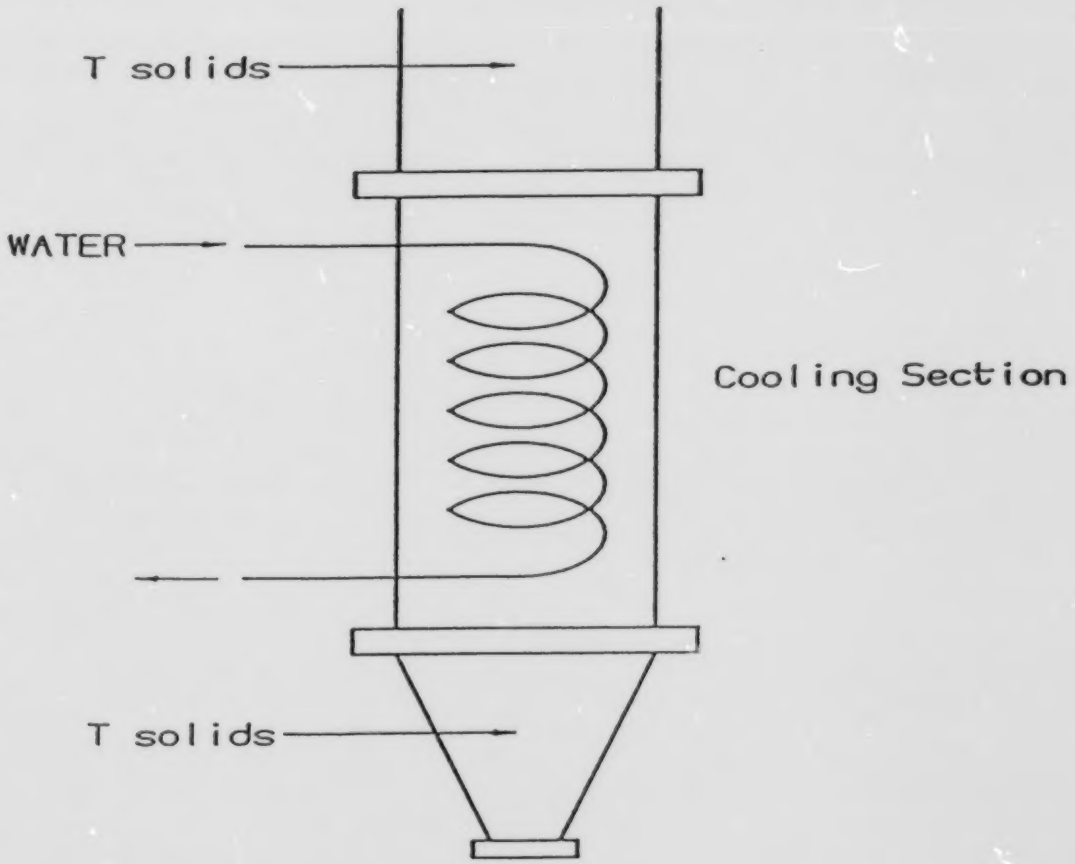
Gas Sampling and Analysis

Continuous on-line monitoring for CO, CO_2, O_2, SO_2 and NO_x was carried out and the averages were recorded hourly. The sampling location is downstream of the flue gas cooling section as shown in Figure 2.

Solids Sampling

Five solid flows were sampled at four-hourly intervals. These are J-valve, bed material, standpipe overflow, secondary cyclone underflow and baghouse dust. When the secondary cyclone is removed from the circuit, the number of samples were reduced to four.

FIGURE 3
DETERMINATION OF THE SOLIDS
RECIRCULATION RATE



$$\text{mass flow of solids} = \frac{Cp_{water} \times \Delta T_{water} \times \text{mass flow water}}{\Delta T_{solids} \times Cp_{solids}}$$

4.0 RESULTS AND DISCUSSION

The scope of the work is outlined in the Statement of Work given in Appendix A. Nine tests were carried out using Minto Coal with a variety of sorbent and test conditions. The sorbents used were Havelock limestone, Havelock hydrated lime and hydrated bed material (H.B.M.).

4.1 Feedstock Characteristics

A bulk sample of approximately 10 tons of Minto coal was dried, crushed and screened to top size of 3/16". The bulk sample was well blended and was large enough to complete all the required tests in this study. The chemical and size analysis of the coal is given in Table 1. The sulphur content of the coal was 6.6% which is typical for Minto coal which have a sulphur content ranging between 5.5 and 8.5%.

The two sorbents used in this study are high purity Havelock limestone and hydrated lime. The chemical and size analysis of the two sorbents are shown in Table 2. For the limestone this particle size distribution has been shown in a previous study carried out at RPC (1) to be the most effective size range. For the hydrated lime this particular size distribution was the only commercially available product from Havelock. Based on past experience with limestones, a coarser size range would have been more preferable.

TABLE 1

Chemical and Particle Size

Analysis of Minto Coal

PROXIMATE ANALYSIS (wt%)	
Moisture	2.99
Ash	13.78
Volatiles	33.62
Fixed Carbon	49.61
ULTIMATE ANALYSIS (wt)	
Carbon	71.00
Hydrogen	4.60
Nitrogen	1.22
Sulphur	6.60
Ash	13.78
Oxygen	2.8
CALORIFIC VALUE (wt%)	
BTU/lb	13,025
SIEVE ANALYSIS (wt%)	
MESH #	
+4 (4.76 mm)	2.9
+9 (2.00 mm)	29.1
+20 (0.481 mm)	34.0
+80 (177 μm)	17.3
+170 (88 μm)	7.1
pan	5.1
	4.5

TABLE 2

Chemical and Particle Size Analysis of

Havelock Limestone and Havelock Hydrated Lime

CHEMICAL ANALYSIS (WT%)	Havelock Limestone	Havelock Hydrated Lime
Calcium	39.54	54.50
CaO	55.36	76.23
$CaCO_3$	98.85	--
$Ca(OH)_2$	--	100
Others	1.15	--
SIEVE ANALYSIS (WT%)		
MESH #		
+14 (1.41 mm)	5.3	--
+18 (1.0 mm)	24.8	--
+20 (841 μm)	11.0	--
+25 (707 μm)	11.9	--
+95 (354 μm)	27.8	--
+100 (149 μm)	12.1	1.0
+140 (105 μm)	--	26.38
+170 (88 μm)	--	55.24
+200 (74 μm)	--	15.28
+400 (37 μm)	--	1.95
pan	7.1	0.15

4.2 Operating Conditions and Test Results

Nine tests were carried out in accordance to the work statement given in Appendix A. Table 3 shows the test matrix and the results for the first seven tests are summarized in Table 4. The raw data, chemical analysis of the output stream, mass balance calculations are shown in Appendix B.

The average chemical composition of selected solid samples are shown in Table 5 and the results are shown graphically in Figure 4. The results show very clearly that the J-valve and the bed sample have almost identical chemical compositions. Based on these results only one of these two samples is necessary to have a representative sample of the bed composition.

The standpipe samples have a markedly different composition from those for the bed sample and J-valve. This result confirms earlier findings which suggest that the standpipe samples are not representative of bed material due to fugitive fine dust particles which find their way into the side port at the top of the standpipe (near the bottom of the primary cyclone, see Figure 2) and report as bed discharge(1).

A brief description on each test is given below and further comments are given in Section 4.3.

Test 1: This was a base line test. The duration of the test was extended in order to produce sufficient bed material to be hydrated for subsequent tests.

Test 2: This was also a base line test, designed to show the effect of dust recycling from the secondary cyclone to the combustors, on sulphur capture.

Test 3: This was a single test using hydrated lime instead of limestone.

TABLE 3
TEST MATRIX FOR THE ASSESSMENT OF ALTERNATIVES FOR THE ENHANCEMENT OF SULPHUR CAPTURE+

Test No.	Sorbent	Humidification Location	Secondary Cyclone Recycle	Test Duration Hrs	Comments
1	L.S.*	No	No	50	Base line test + produce enough bed material for subsequent tests.
2	L.S.	No	Yes	16	Base line test.
3	Hydrated lime	No	No	16	Effect of sorbet type.
4	L.S.+ H.B.M**	No	No	16	Effect of hydrated bed material.
5	As Test #4, but different ratio	No	No	16	Effect of L.S./H.B.M. ratio.
6	L.S.	Combustor Location #1	No	20	Effect of combustor humidification.
7	L.S.	Combustor Location #2	No	12	Effect of combustor humidification location.
8	L.S.	Flue Gas Cooler	No	16	Effect of low temperature humidification.
9	L.S.	Flue Gas Cooler	Yes	20	Effect of recycling humidified bed material.

+Other operating parameters such as bed temperature, air distribution, are as follows:

Bed Temperature	850°C
Operating Velocity	7 m/s
Ca/S Ratio	2:1
Limestone type	Havelock
Mean Particle Size	400 μm
Air Distribution	60% primary
	40% others (aeration and transportation)
Circulation Rate	700-1000 kg/hr

* L.S. = Limestone

** H.B.M. = Hydrated bed material

TABLE 4
OPERATING CONDITIONS, MEASURED AND CALCULATED PARAMETERS

Parameter	Test No.						
	1	2	3	4	5	6	7
Feedrates, kg/h:							
Coal	8.86	9.12	8.42	8.71	8.35	9.34	8.64
Limestone	3.69	3.80	2.57	---	1.75	3.90	3.60
H.B.M.	---	---	---	8.71	4.18	---	---
Air	101.15	100.35	100.52	101.57	101.10	102.62	101.36
Ca/S Ratio	2:1	2:1	2:1	2:1	2:1	2:1	2:1
Air Distribution, %:							
Primary	60.7	59.1	54.2	60.1	61.1	55.4	53.1
Others	39.3	40.9	45.8	39.9	38.9	44.6	46.9
Measured Parameters:							
Bed Temperature, C	862	868	876	867	865	877	877.40
Discharge Rate, kg/h:							
Bedsample	0.43	0.32	0.31	0.26	0.17	0.28	0.28
Standpipe	1.29	1.36	0.11	6.83	2.94	0.24	0.21
Baghouse	2.42	0.45	1.98	3.57	3.60	5.23	4.81
Cyclone	0.00	0.65	0.31	0.00	0.00	0.00	0.00
J-Valve	0.09	0.04	0.06	0.12	0.05	0.03	0.03
Cyclone Recycle, kg/h	0	33	0	0	0.00	0	0.00
Gas Composition:							
CO2 %	15.83	15.61	14.60	13.86	14.04	14.30	13.05
O2 %	3.23	3.13	3.59	3.00	4.12	4.18	4.68
CO ppm	524.7	178.8	504.6	291.3	206.5	250.3	129.5
SO2 ppm	1526.5	709.1	794.3	1231.3	650.0	1235.7	1380.8
NOx ppm	231.0	253.3	240.0	221.8	240.5	48.1	185.2
Calculated Parameters:							
Excess Air, %	15	12.2	20.26	17.44	21.91	10.64	18.16
Sulphur Capture, %	71.6	87.2	84.7	83.3	87.3	77.8	74.0
Carbon Utilization, %:							
Solid Basis	92.98	98.83	95.36	93.11	94.82	88.95	92.15
Gas Basis	96.85	92.04	98.57	88.42	95	84.93	81.38

TABLE 5
AVERAGE CHEMICAL COMPOSITION OF SELECTED SOLID SAMPLES

TEST NO:	STREAM	CHEMICAL SPECIES			
		TOTAL CARBON (%)	TOTAL CALCIUM (%)	TOTAL SULPHUR (%)	ASH (%)
1	BED-SAMPLE	0.09	34.57	15.91	99.41
	J-VALVE	0.16	33.14	15.38	99.32
	STANDPIPE	14.20	26.87	8.30	82.36
	BAGHOUSE	12.71	26.74	8.00	81.23
2	BED-SAMPLE	0.06	31.68	14.19	99.32
	J-VALVE	0.04	30.97	14.08	97.99
	STANDPIPE	1.63	31.56	12.76	91.47
	BAGHOUSE	10.14	20.04	7.58	86.22
3	BED-SAMPLE	0.06	28.29	12.62	99.40
	J-VALVE	0.09	27.78	12.34	98.86
	STANDPIPE	5.89	27.20	11.00	91.97
	BAGHOUSE	12.84	23.79	8.57	85.23
4	BED-SAMPLE	0.38	23.46	12.73	98.89
	J-VALVE	0.34	27.18	14.87	98.69
	STANDPIPE	0.80	24.78	14.62	97.39
	BAGHOUSE	11.59	20.96	11.62	83.87
5	BED-SAMPLE	0.20	20.84	14.00	98.93
	J-VALVE	0.68	25.09	16.25	98.43
	STANDPIPE	1.05	22.70	15.14	97.52
	BAGHOUSE	11.51	20.35	9.73	83.83
6	BED-SAMPLE	0.84	31.53	13.12	99.07
	J-VALVE	0.82	33.04	13.81	98.83
	STANDPIPE	7.52	31.22	12.10	88.10
	BAGHOUSE	16.34	26.14	8.07	81.52
7	BED-SAMPLE	0.34	33.69	16.06	99.51
	J-VALVE	0.21	33.99	16.22	99.54
	STANDPIPE	3.31	33.26	13.69	92.27
	BAGHOUSE	12.22	26.93	8.74	86.57

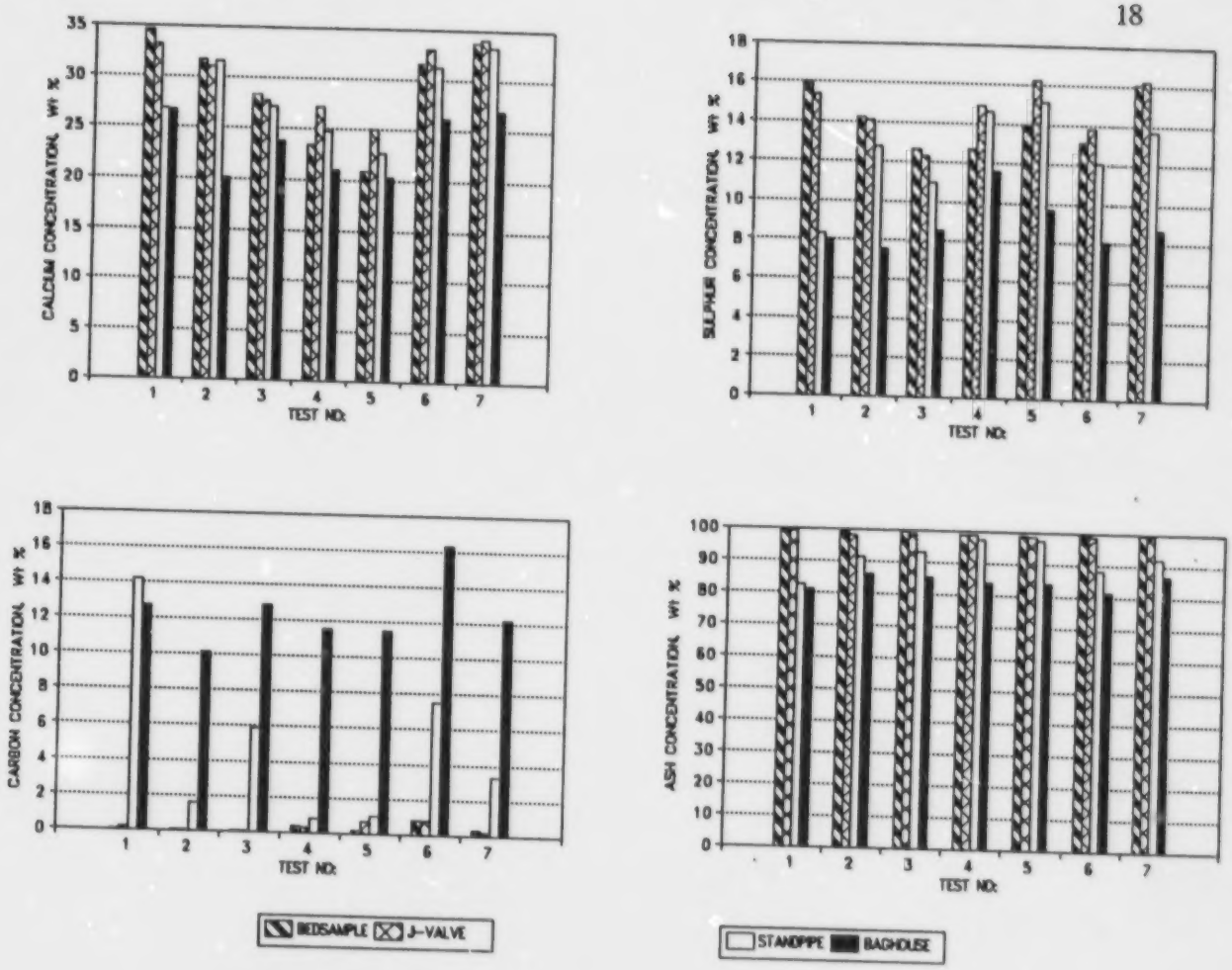


FIGURE 4

AVERAGE CHEMICAL COMPOSITION FOR SELECTED SOLID SAMPLES

Test 4: Bed material from Test #1 was analyzed for available calcium, hydrated and blended with the coal to give a Ca/S ratio of 2:1. No limestone was used in this test, i.e. all the calcium was supplied from the hydrated bed material (H.B.M.).

Hydration of bed material was carried out by stirring the material in boiling water for 2 hours followed by filtration, drying and screening. The composition and particle size of the hydrated bed material is shown in Table 6. A study by Ontario Hydro on waste reactivation showed that hot hydration is necessary in order to reactivate the waste (2). The exact mechanism for waste reactivation is not known. However, in order to gain some appreciation of the effect of water temperature on waste activation a small sample was hydrated cold and hot and the results are shown in Appendix C. Hot hydration led to slightly higher degree of conversion to calcium hydroxide. The difference in the degree of conversion to calcium hydroxide was not significant which tends to suggest that under hot conditions some physical changes in the particle structure may be taking place adding to the particle reactivity.

Test 5: This test was similar to Test #4 i.e. a Ca/S ratio of 2:1. The only difference is that half the calcium in the feed was from H.B.M. and the other half was from limestone.

Test 6: This test was carried out with water sprayed directly into the combustor (high temperature humidification). The water spray was injected at a location 8" above the distributor plate i.e. in the reducing zone of the combustor. The spray nozzle used throughout this study is a Turbotak Caldyn 2mm nozzle, the specification of which is given in Appendix D.

The nozzle was operated on air pressure of 60 psig and water flowrate was adjusted at 17 cc/min, which was calculated to provide the

TABLE 6

Chemical Composition and Particle Size Analysis of Bed Material and Hydrated Bed Material

Chemical Species, wt% Description	Bed Material	Hydrated Bed Material
Total C	1.40	1.02
Org. C	0.35	<0.05
S	10.58	9.01
Ca	28.60	27.88
$CaCO_3$	8.75	8.50
CaO	13.52	<0.1
$Ca(OH)_2$	3.70	28.49
$CaSO_4$	45.70	30.87
Sieve Analysis (wt%)		
+16 mesh	3.18	2.82
-16 +25 mesh	13.51	9.54
-25 +45 mesh	39.45	36.19
-45 +200 mesh	39.48	41.98
-200 +325 mesh	2.13	4.39
-325 +400 mesh	0.40	1.64
-400 mesh	1.84	3.43

stoichiometric water requirement to convert all the CaO in the feed (resulting from the calcination of the limestone) into $Ca(OH)_2$.

Test 7: This was similar to Test #6 except for the location of the spray nozzle. It was located 60" above the distributor plate i.e. in the oxidizing zone of the combustor.

Test 8: In this test low temperature humidification was carried out in the flue gas cooler. The operating parameters were selected based on the best available information in the literature. Caking problems however were not solved despite several attempts at overcoming these problems. More details are given below in Section 4.3.

Test 9: This test was similar to Test #8, but with secondary cyclone recycling. This test was designed to show whether additional calcium utilization could be achieved as a result of recycling hydrated material into the combustor. As in Test #8 there was caking problems.

4.3 Operating Experience

The first seven tests were carried out with very little or no operational problems. From an operational standpoint these tests were similar to previous work carried out at RPC. Therefore, the test procedures were well established and refined over thousands of hours of operation. Among these tests, only Tests 6 and 7 involved a new aspect, namely combustor humidification. There were no operational problems.

In Tests 8 and 9, there were no problems in the operation of the combustor itself but persistent problems were encountered in the cooling section. The cause of the problem was caking of the fine dust as a result of the water spray. Several attempts were made at solving the caking problem which included modification of the cooling section, changing the operating conditions and cold tests using a plexiglass model.

4.3.1 Humidification Section - One Column Configuration

Two configurations of the cooling section were tested. The original configuration consisted of a single column which is made of two concentric pipes of a nominal diameter of 15 cm (6") and 20 cm (8"), respectively. The height of the column is 5.2 m (17'). The water spray nozzle was fitted on the top of the column.

The gas temperature and relative humidity are among the important parameters affecting sulphur capture in a cool side desulphurization process. The optimum conditions for the Ontario Hydro study(3), together with the operating conditions from the present study are as follows:

	Ontario Hydro Study	Present Study
• Inlet temperature, °C	147 - 153	400-450
• Outlet temperature, °C	60 - 65	150-200
• Relative humidity at, % at injection site	60%	Varied widely

Under the operating conditions given above some reduction in SO_2 concentration in the flue gases was observed. However, due to the caking problems the tests could not be run for sufficient length of time to quantify, with confidence, the degree of sulphur reduction.

The caking problems were attributed to the wrong temperature regime and the water spray characteristics i.e. particle size distribution, spray angle and nozzle alignment. To overcome these problems the cooling section was modified to cool the flue gases sufficiently before the humidification process. Also, a plexiglas model was set-up in order to make some qualitative assessment of the spray pattern.

4.3.2 Plexiglass Model Study

In a cool side desulphurization process, partially sulphated sorbent from the combustor is activated by a water spray. The process has been shown to be sensitive to water droplet size, initial humidity level and residence time in the humidifier (3). It is also suggested that unreacted sorbent particles are activated primarily due to inertial impactions and interception of the dry sorbent particles and water droplets resulting in the formation of highly active slurry droplets. It is also suggested that there is an optimum size range which gives the best activation efficiency(4). A very large droplet would not achieve complete evaporation leading to loss of activation efficiency and caking problems, while too small droplets will evaporate too rapidly to be effective. In a study carried out by Ontario Hydro a number of spray nozzles

TABLE 7*

NOZZLE SELECTION

120 cc/min water

50 - 60% relative humidity

75 - 80 psig air pressure

NOZZLE TYPE (TWO FLUID)	SPRAY ANGLE, °	MEAN DROPLET SIZE, μm	DROPLET DRYING TIME, S	OBSERVATION	INCREMENTAL SO_2 REMOVAL,
Turbotak Caldyn 2 mm	-12 - 15	5 - 10	-0.9	No Caking	18
Sonic Development ST-47	-15 - 20	20 - 30	-1.3	Caking	12
Sonic Development 052 MBX-1	-15 - 20	20 - 30	-	Severe Caking	-
Spraying System 1/4 J	-18	10 - 25	-1.3	No Caking	11

Front End Conditions: Infurnace Beachville Limestone Injection

Inj Temp ~1100°C

Ca/S Mole Ratio: 3.0

Limestone Particle Size ~8.6 μm MMD

SO_2 Removal ~40 - 43%

*reproduced from Reference(3).

were tested, and the results are summarized in Table 7(3). The data indicates that the Turbotak Caldyn 2 mm nozzle has the most favourable spray characteristics. The results also show that a relatively small deviation in the mean particle size could lead to severe caking problems. In this study the Turbotak Caldyn nozzle was used and was operated at air pressure of 60 psig, as recommended by the nozzle supplier. The diameter of the humidification chamber used in the study was 6" which is identical to that used in the Ontario Hydro Study (3).

A cold test rig was set up to make some visual observations of the spray pattern. The rig was made of a 6" plexiglass tube and was fitted with the same spray nozzle as in the hot study. Cold air was introduced to simulate the flue gas and therefore the effect of temperature and dust particles on the spray pattern could not be simulated.

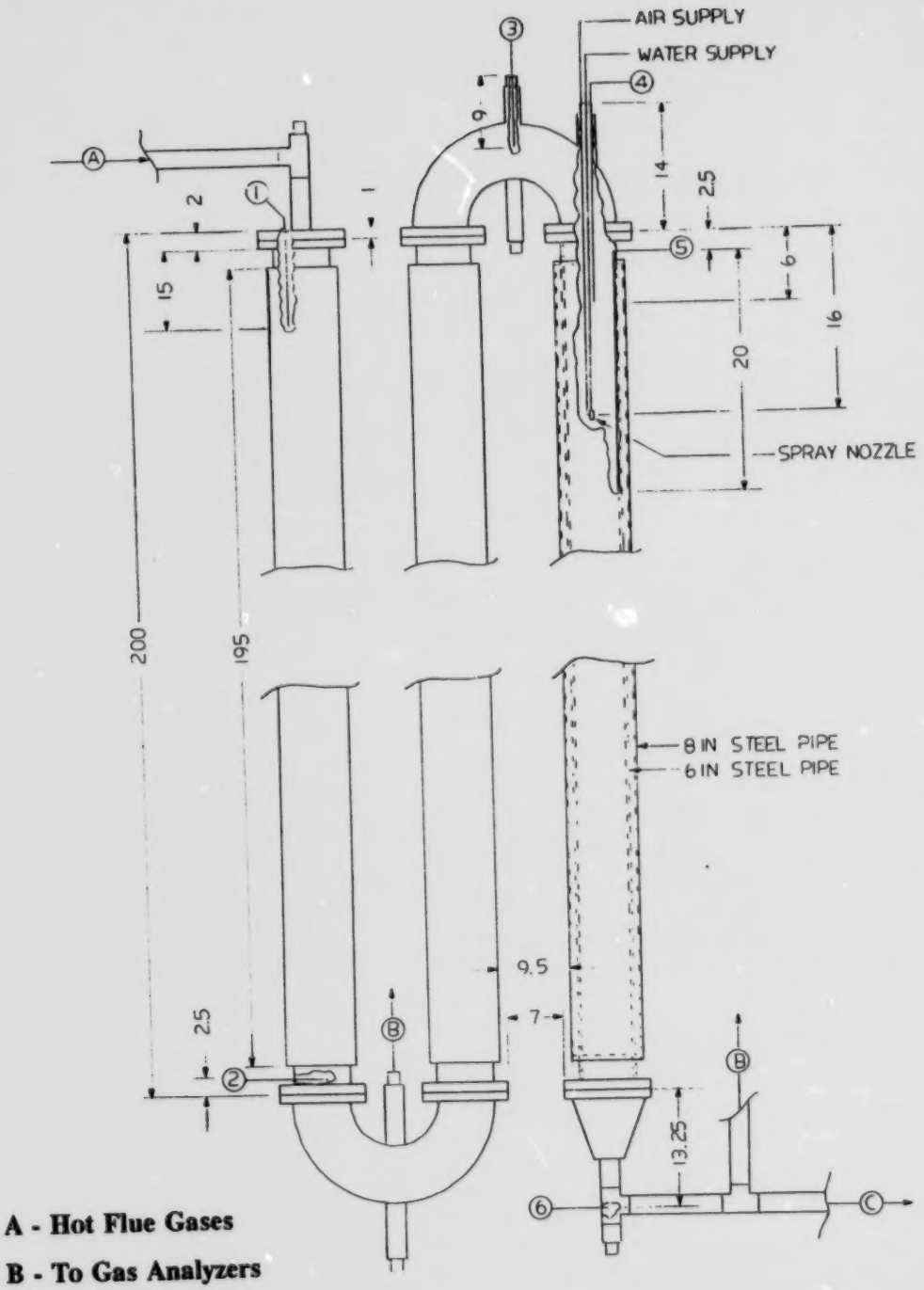
Visual observations showed the spray to have a narrow angle. Also, by adjusting the air pressure to 60 psig or higher, a fine spray was achieved and wetting of the column wall appeared to be less of a problem,

The observations given above were all that can be achieved without an elaborate set up to quantify particle size distribution which was outside the scope of the present study.

4.3.3 Modified Humidification Section - Three Columns Configuration

In order to achieve the appropriate flue gas temperature profile, the cooling section was modified to include two more cooling columns as shown in Figure 5. The cooling section was also fitted with a number of thermocouples.

A typical temperature profile with and without water is shown in Figure 6. Among the six temperatures shown thermocouples 4 and 6 show the inlet and outlet



A - Hot Flue Gases

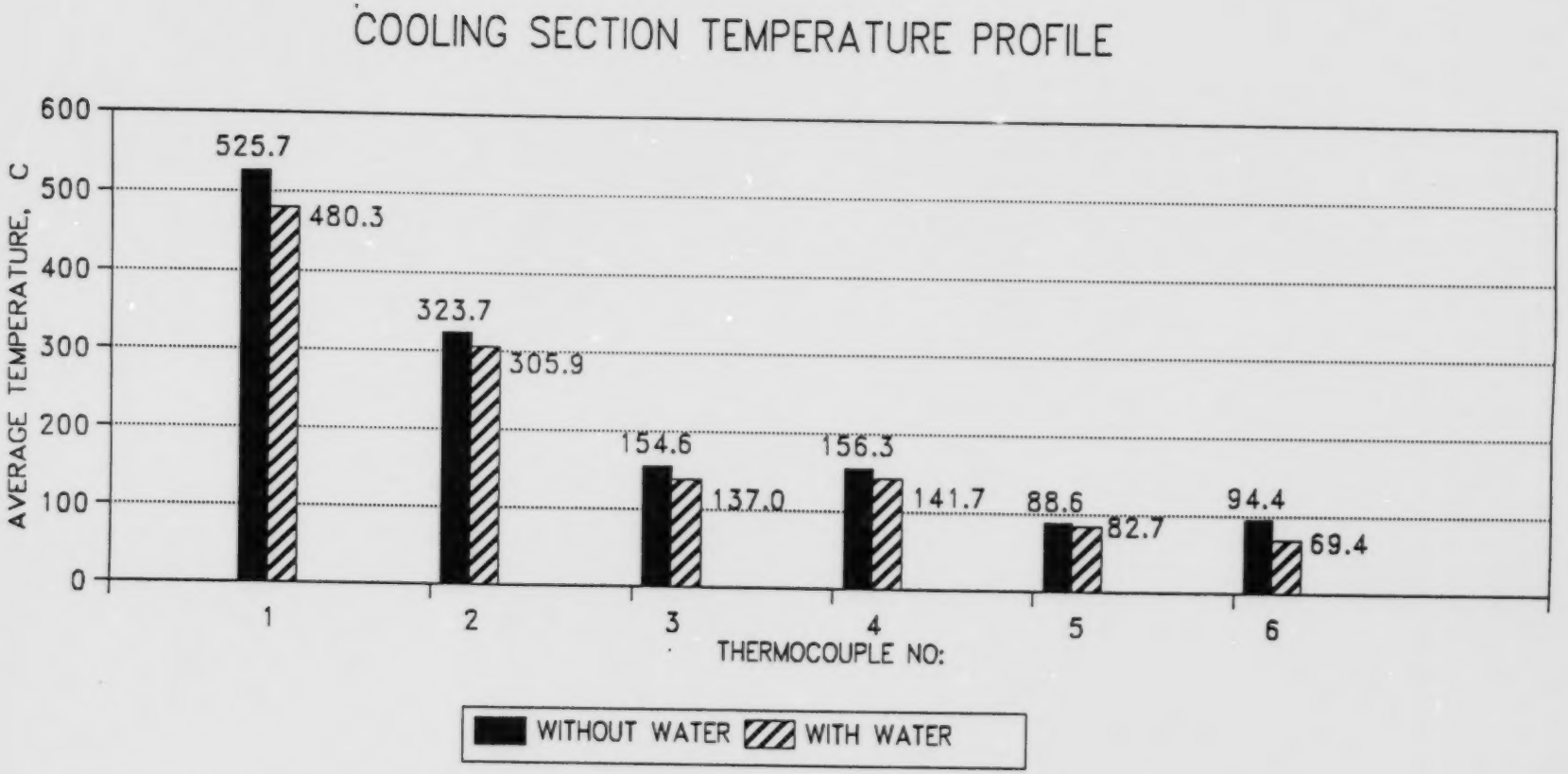
B - To Gas Analyzers

C - To Cyclones and Baghouse

FIGURE 5

SCHEMATIC OF THE COOLING SECTION SHOWING LOCATION OF THE SPRAY NOZZLE AND THERMOCOUPLES

FIGURE 6


COOLING SECTION TEMPERATURE PROFILE
AVERAGE TEMPERATURE, C
600
500
400
300
200
100
0
525.7
480.3
323.7
305.9
154.6
137.0
156.3
141.7
88.6
82.7
94.4
69.4
1
2
3
4
5
6
THERMOCOUPLE NO:
WITHOUT WATER
WITH WATER

temperature of the flue gases. Note that thermocouple 5 shows lower temperatures than thermocouple 6. This is probably due to the position of thermocouple 5 close to the wall of the cooling section. Thermocouple 5 could also be affected by the spray.

As a result of this modification the appropriate flue gas inlet and outlet temperatures have been achieved. The caking problems however were not solved and the photographs given in Figure 7 show the extent of the problem. The caking problem, limited the duration of the test runs to such an extent that it was not possible to draw firm conclusions on the effectiveness of the cool side desulphurization. However, the results shown in Figure 8 indicate that the SO_2 emission decreased from approximately 1100 ppm to 450 ppm as a result of humidification. The corresponding sulphur capture is estimated to be 78% (without water spray) to 91% (with water spray). It is entirely possible that upon optimization higher enhancement of sulphur capture could be achieved.

4.4 Sulphur Capture

The test matrix shown in Table 3 was designed such that the effect of a number of operating parameters on sulphur capture could be identified. Those under consideration were secondary cyclone recycle, sorbent type, high temperature humidification and cool side humidification. To achieve these objectives the parameter under consideration was varied while minimizing changes in other operating conditions such as bed temperature, operating velocity and Ca/S, etc. The results shown in Table 4 show clearly that this approach was implemented successfully. A previous study carried out at RPC showed that small deviations in bed temperature, excess air and air distribution have no significant effect on sulphur capture(1).

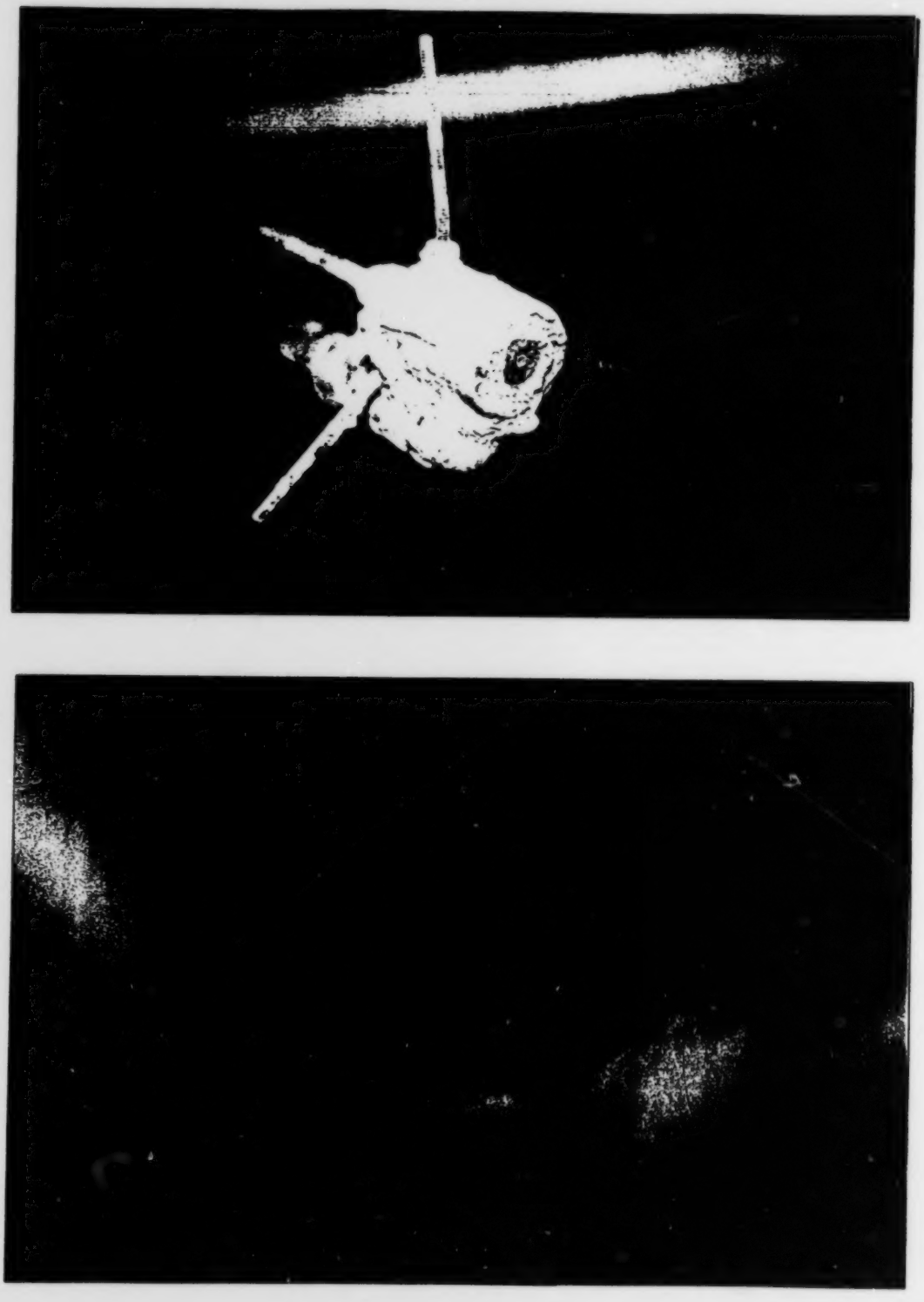
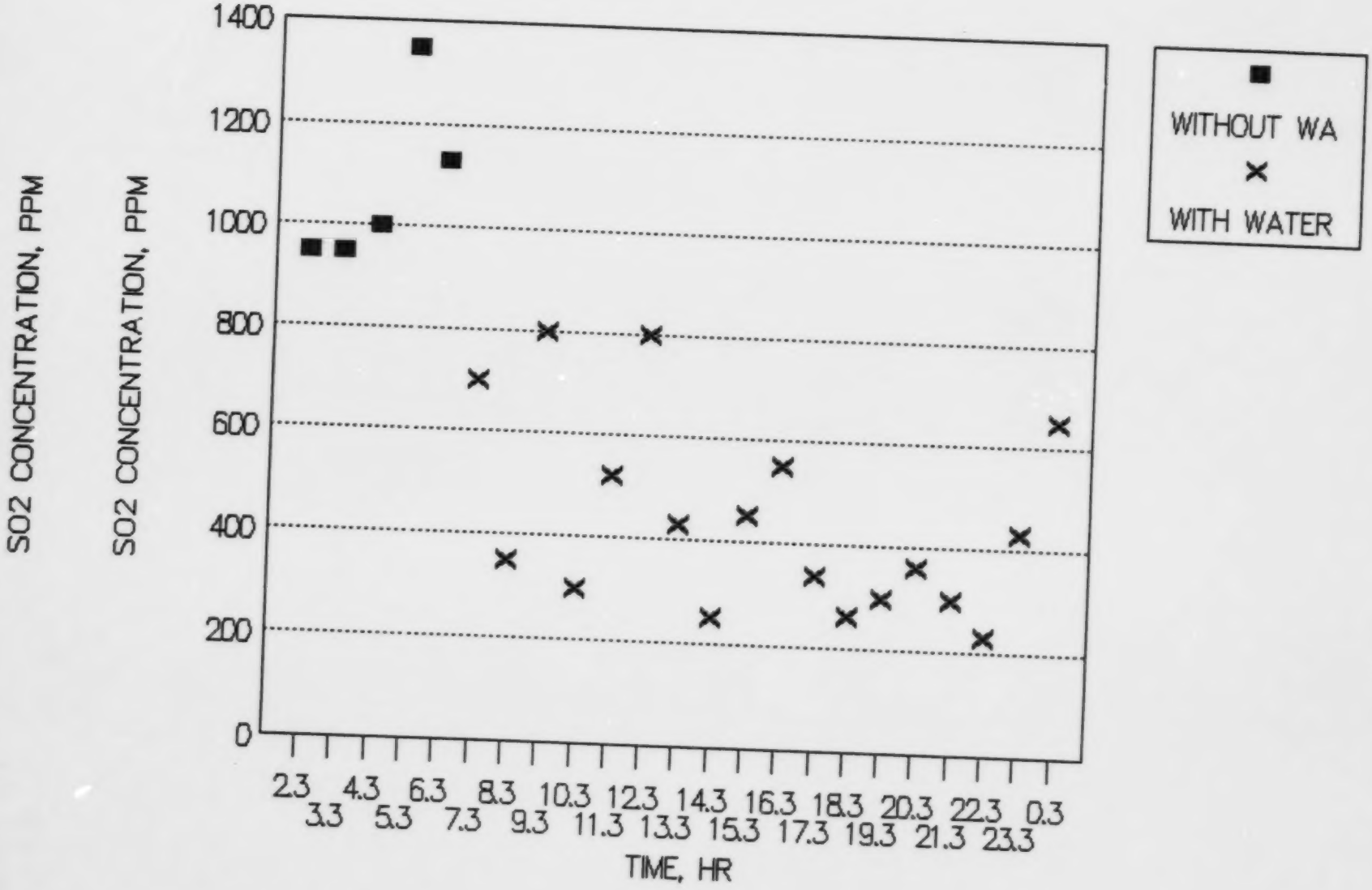


FIGURE 7: PHOTOGRAPHS SHOWING CAKE BUILD UP ON THE SPRAY NOZZLE AND ON THE SIDES OF THE COOLING SECTION

FIGURE 8

SULPHUR DIOXIDE CONCENTRATION WITH AND WITHOUT WATER SPRAY



4.4.1 Effect of Secondary Cyclone Recycle on Sulphur Capture

The sulphur capture results for Tests 1 to 7 are shown in Figure 9. Test 1 was the base run and the degree of sulphur capture was 71.6% at a Ca/S ratio of 2:1. In Test 2 recycling of the dust from the secondary cyclone back to the combustor gave rise to a significant improvement in sulphur capture to 87.2%. These results are consistent with previous work at RPC where the sulphur capture improved from 74% to 87% under similar operating conditions(1).

4.4.2 Effect of Sorbent Type on Sulphur Capture

In Test #3 hydrated lime was used as the sorbent. The Ca/S ratio was monitored at 2:1 and the sulphur capture was 84.7%. The improvement in sulphur capture from the base run (71.6%) is due to the higher reactivity of the hydrated lime as compared to limestone. The particle size of hydrated lime was very fine and consequently the particle residence time in the combustor is reduced significantly, leading to lower calcium utilization. Despite this fact and because of the higher reactivity of hydrated lime a high sulphur capture (high calcium utilization) was achieved.

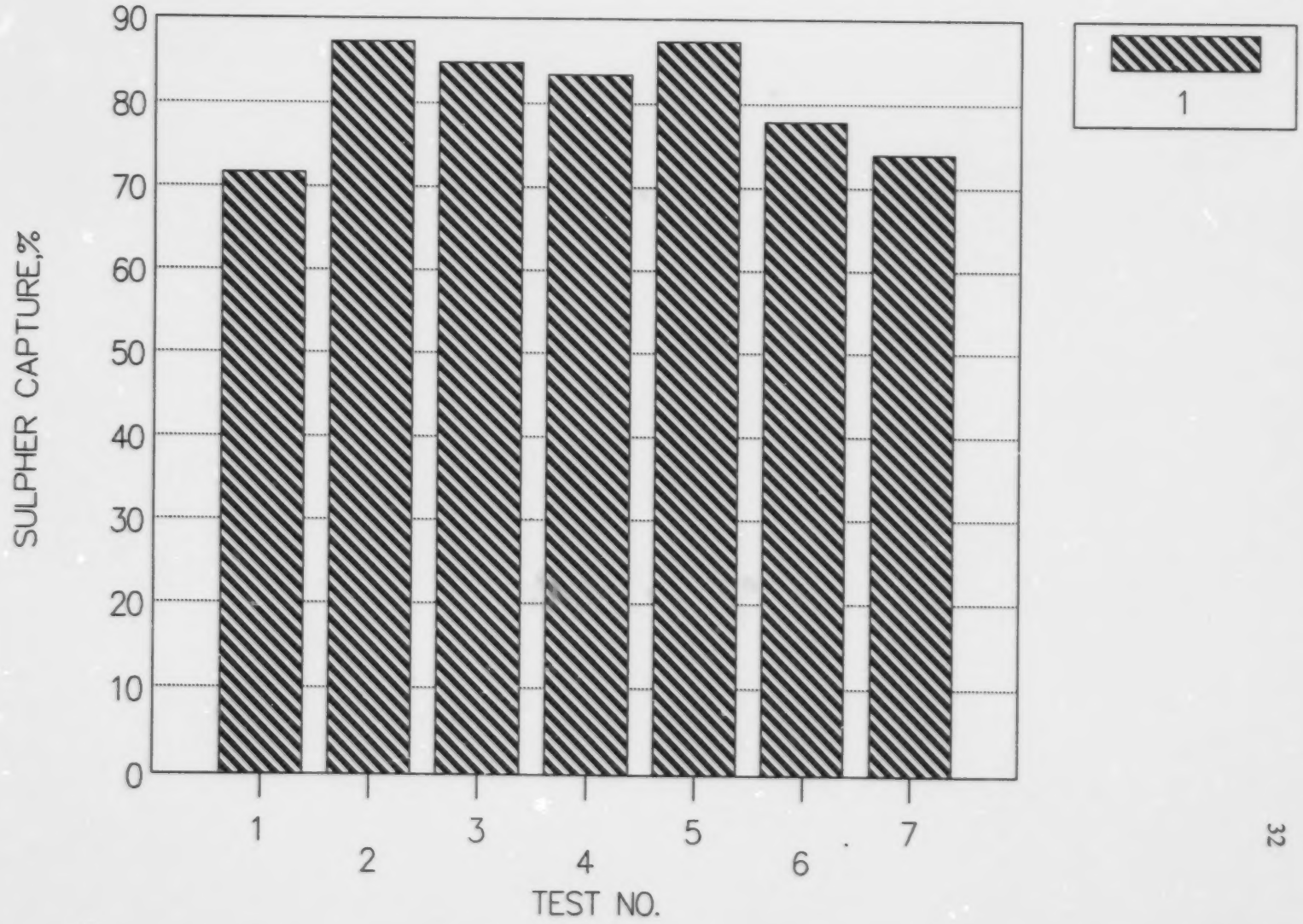
The cost of hydrated lime is estimated at approximately five times that of limestone. Therefore, from an economic perspective, the use of hydrated lime is not a viable alternative.

4.4.3 Effect of Hydrated Bed Material Injection on Sulphur Capture

Bed material from Test #1 was hydrated in hot water as outlined earlier in Section 4.2. The analysis of the original and hydrated bed material is shown in Table 6. In Test 4 all the calcium was originated from hydrated bed material while in Test 5 the source of calcium was equally divided between hydrated bed material

FIGURE 9

DEGREE OF SULPHUR CAPTURE FOR TESTS 1 THROUGH 7



and limestone. In both tests a markedly high sulphur capture was achieved, 83.3 and 87.3% for tests 4 and 5, respectively. These values are much higher than the base case represented by Test 1. The improvement in sulphur capture suggests that the hydrated bed material is a more reactive sorbent than limestone.

For both tests 4 and 5 Table 4 shows that the standpipe and baghouse discharge rates are higher than the other tests, reflecting the increased amount of ash in the feed materials. The residence time of the solid particles in the bed is inversely proportional to the ash content in the feed material and this could be a possible explanation for the higher sulphur capture achieved in Test 5 as compared to Test 4 (The ash content in the feed for Test 5 was lower than that for Test 4.). If this is the case, beneficiation of the bed material could produce a highly reactive sorbent and a substantial reduction in limestone requirement.

4.4.4 Effect of Combustor Humidification on Sulphur Capture

In Tests 6 and 7, high temperature humidification was carried out as discussed earlier in Section 4.2. In these tests the sulphur capture as shown in Figure 9, was higher than the base case (Test 1). In Test 6 the sulphur capture was higher than in Test 7 indicating that humidification location does have an impact on the degree of sulphur capture. In Test 6 the spray was injected 8" above the distributor plate in the reducing zone of the combustor, while in Test 7 the spray was injected 60" above the distribution plate in the oxidizing zone of the combustor. The higher sulphur capture in Test 6 could be attributed to the combustion atmosphere or to the increased residence time of the water vapour. The relative significance of these two parameters cannot be determined from the available data.

Regardless of the injection location the improvement in sulphur capture as a result of combustor humidification is not very significant. Therefore this alternative should be a low priority in any future investigations.

4.4.5 Effect of Cool Side Humidification on Sulphur Capture

As mentioned earlier in Section 4.3, the results of cool side humidification are not conclusive, and caking problems were not solved despite considerable efforts to do so. The caking problems must be taken into consideration in any future attempt to apply this alternative. The other point worthy of consideration is the low temperature of the flue gases (~65 °C) exiting the humidification chamber. Such low temperatures could present problems in the baghouse unless the gases are reheated to prevent conditions and to give adequate plume rise in the stock.

5.0 CONCLUSIONS AND RECOMMENDATIONS

In this section the general conclusions which have emerged from this study will be given, as well as recommendations for future work.

5.1 Conclusions

The main conclusions of this study are as follows:

- Recycling of the dust from the secondary cyclone back into the combustor have led to a significant increase in sulphur capture from approximately 72% to 87%. The rate of dust recycled was approximately 3 times the feedrate.

- The use of hydrated lime instead of limestone has led to a significant improvement in sulphur capture from approximately 72% to 85%. This improvement however is not sufficiently large to make the use of hydrated lime an economically viable alternative.

- Hydrated bed material was shown to be a more reactive sorbent than fresh limestone. The sulphur capture using hydrated bed material at Ca/S ratio of 2:1 is 83% compared to 72% for limestone with similar operating conditions.

- High temperature humidification at the reducing zone of the combustor have led to some improvement in sulphur capture. The improvement however is not sufficiently large to warrant future consideration.

- No firm conclusions could be drawn on cool side humidification. Caking of the dust around the water spray nozzle was the main difficulty encountered with this process.

5.2 Recommendation for Future Work

Future research and development work is required in order to enhance our current understanding of a number of important issues. Those identified in this study are as follows:

- Bed material was reactivated by hydration and was shown to be a very effective and highly reactive sorbent. The mechanism by which the particles were reactivated have not received sufficient attention and are worthy of further consideration. Also further combustor tests should be carried out to confirm the findings of this study.

- Reactivation of other waste streams such as baghouse dust should be evaluated. In circulating fluidized bed systems, the baghouse dust is by far the largest solid waste stream. The waste may be activated by hydration as was the case in this study or injection of the dust into the combustor as an aqueous spray. In the latter mode of operation the waste is reactivated through the rapid evaporation of water leading to particle disintegration and the development of porous fragments having high surface area. Waste activation and re-injection are ideally suited for retrofit applications and could offer cost advantages over other competing options.

- Cool side humidification is worthy of future consideration. Special attention should be given to the optimization of the spray characteristics and its interaction with the solid particles as well as the design of the humidification chamber.

6.0 REFERENCES

1. P. Salib, "Investigation of Sulphur Capture During Circulating Fluidized Bed Combustion of Eastern Canadian Coals", RPC Report No. MDP/88/17, March 1989.

2. R. Mangal, Ontario Hydro, Private Communication, April 1990.

3. Mozes; M.S., Mangal, R.; Thampi, R. and Tubman, D., "Sorbent Injection for SO_2 Control", Ontario Hydro Research Division, Report No. 88-63-K, August 1988.

4. Ahlbeck, J.R., "On Sorbent Activation in Coolside Desulfurization", J. Air Waste Management Assoc., V. 40, No. 3, p. 345-351, March 1990.

APPENDIX A

Statement of Work

APPENDIX "A"

STATEMENT OF WORK

TITLE: Enhancement of Sulphur Capture in Circulating Fluidized Bed Combustion

1.0 BACKGROUND

Sorbents are used to capture SO_2 produced while burning high sulphur coals in fluidized bed combustors (FBC). Recently a study (DSS Contract No. 23440-7-9063/01SQ), was carried out in the pilot-scale circulating fluidized bed combustion at Research Productivity Council in New Brunswick, with minto coal and havelock linestone. The test results indicate that calcium utilization is in the 40% to 50% range for about 90% sulphur capture. The results in general are comparable from those observed in 22 MWe circulating FBC boiler at Chatham, N.B.

An improvement in calcium utilization would lead to a reduction in both the capital and operating costs of a boiler. At the front end, this would result in saving on reagent costs, handling, and feeding systems. While at the back end saving would result from lower dust loading, ash handling and lower disposal costs. Increased calcium utilization would be beneficial to the overall economics of the process.

Improvement of sulphur capture (calcium utilization) in circulating fluidized bed combustion may be achieved through use of more reactive sorbent, additives or by process modification. Those to be examined in this project include reinjection of hydrated bed material, use of hydrated lime and humidification.

2.0 OBJECTIVES

Preliminary assessment of three alternatives, as outlined in the Scope of Work, for enhancement of sulphur capture in circulating fluidized bed combustors.

3.0 SCOPE OF WORK

Three alternatives given below will be examined in the pilot-scale circulating FBC at RPC.

A) Use of hydrated lime. A single test is planned in order to get an indication of how effective hydrated lime would be and whether or not additional work is justified.

B) Use of hydrated bed material. Two tests are planned using different limestone/hydrated bed material ratios (L.S./H.B.M.).

C) Use of humidification. High temperature humidification will be tested by spraying water directly into the combustor while low temperature humidification will be carried out at the flue gas cooler.

4.0 PROJECT EXECUTION

The project will be subdivided into several tasks as described below.

Task 1: System preparation

System preparation will consist of routine maintenance, and one modification. The former will include replacement of broken thermocouples, cleaning and recalibration of flow meters, etc.

The only modification necessary is to install a solids removal port within 5"-6" above the distributor plate, which will permit collection of bed material, representative of that from a large-scale unit.

Task 2: Feed Preparation and Characterization

The feedstocks which will be acquired, prepared and characterized consist of 5 tons of Minto coal, with 7% to 8% sulphur, 2 tons of Havelock limestone and 0.2 ton of hydrated lime.

Feed preparation may include drying, crushing and screening as appropriate. Feedstock characterization will consist of particle size distribution, ultimate, proximate and ash analysis.

Hydration of bed material; this may include wetting, drying, screening and particle size analysis.

Task 3: Test Runs

Nine tests are planned for this project. A test matrix is given in Table 1. Other operating conditions will be based on previous test results. After test with hydrated material (tests 4 & 5) results will be discussed with CANMET's Scientific Authority for continuing further test work. If no improvement in sulphur capture is observed, the remaining test program may be discontinued or modified. Tests are to be conducted as outlined and any changes require prior approval of the Scientific Authority.

TABLE 1
TEST MATRIX FOR THE ASSESSMENT OF ALTERNATIVES FOR THE ENHANCEMENT OF SULPHUR CAPTURE

Test No.	Sorbent	Humidification Location	Secondary Cyclons Recycle	Test Duration Hrs.	Comments
1.	L.S.*	No	No	50	Base line test - produce enough bed material for subsequent tests.
2.	L.S.	No	Yes	16	Base line test.
3.	Hydrated lime	No	No	16	Effect of sorbent type.
4.	L.S. + H.B.M.**	No	No	16	Effect of hydrated bed material.
5.	As Test #4, but different ratio	No	No	16	Effect of L.S./H.B.M. ratio.
6.	L.S.	Comb. Location #1	No	20	Effect of combustor humidification.
7.	L.S.	Comb. Location #2	No	12	Effect of combustor humidification location.
8.	L.S.	Flue Gas Cooler	No	16	Effect of low temperature humidification.
9.	L.S.	Flue Gas Cooler	Yes	20	Effect of recycling humidified bed material.

+ Other operating parameters such as bed temperature, air distribution, velocity Ca/S ratio will be constant and will be selected based on previous experience and in consultation with the Scientific Authority.

* L.S. = Limestone

** H.B.M. = Hydrated bed material

Bed Temperature	850 C
Operating Velocity	7 m/s
Ca/S Ratio	2:1
Limestone type	Havelock
Mean Particle Size	400 micron
Air Distribution	60% primary 10 secondary 30% others (aeration and transportation)
Circulation Rate	700-1000 kg/hr

A brief comment on each test is given below.

Test 1: This is a base line test. It is also designed to produce sufficient bed material which will be hydrated for subsequent tests. Based on the conditions given above. The rate of production of bed overflow would be approximately 1 kg/hr.

Test 2: This is also a base line test, but with dust recycling from the secondary cyclone.

Test 3: This will be a single test using hydrated lime instead of limestone. Particle size distribution will depend on availability.

Test 4: Bed material and possibly some of the baghouse material from Test #1, will be analyzed for available calcium and blended with the feed. The amount of limestone in the feed will be adjusted to give a Ca/S ratio of 2:1. The ratio will reflect the rate of production of bed material as determined in Test 1.

Test 5: Same as Test #4 but probably with a lower limestone/hydrated bed material ratio (L.S./H.B.M.).

Test 6&7: The effect of combustor humidification will be tested at two locations. The exact locations will be determined in consultation with the Scientific Authority.

Test 8: The low temperature humidification will take place in the flue gas cooler. This process has been shown to be sensitive to the level of humidification, spray particle size distribution and temperature profile. No attempt, will be made at optimization, however, the selection of the operating conditions will be based on available literature. The latter, however, deals mainly with applications to in-furnace sorbent injection for sulphur capture resulting from pulverized fuel burners.

Test 9: Same as Test #8, but with secondary cyclone recycling. This test is designed to show whether additional calcium utilization could be achieved as a result of recycling hydrated material into the combustor.

Tests will be carried out sequentially, with sufficient transition period between tests to reach a steady state operation. Gas composition (particularly SO_2 concentration) and bed temperature are the two main indicators used to signal the end of the transition period. For each test the experimental measurements and analysis will be carried out as follows:

Solids Flow Rates

(a) Feed, Standpipe Overflow, Baghouse Dust

These measurements will be taken every hour.

(b) Secondary Cyclone Recycle

This measurement will be taken every four hours in order to minimize the disruption to the circuit. To take this measurement, the stand-by secondary cyclone will be brought on-line and the underflow was collected for a given period of time (typically 5 min).

(c) Solids Recycle Rate Through Standpipe

The recycle rate will be calculated every hour by carrying out a simple heat balance calculation.

Air Flow Rate

Primary air and secondary air flows to the combustor will be recorded every hour. Also recorded at hourly intervals were lift and aeration air to the J-valve, feeder air and transport and aeration air for the secondary cyclone recycle will also be recorded at hourly intervals.

Temperatures

Temperatures will be recorded hourly at several locations in the combustor and the standpipe.

Gas Sampling and Analysis

Continuous on-line monitoring for CO, CO_2, O_2, SO_2 and NO_x will take place with the averages recorded hourly. The sampling location is downstream of the flue gas cooling section as shown in Figure 2. A grab sample will be collected for N_2O analysis.

Solids Sampling

Five solids flows will be sampled at four-hourly intervals. These are J-valve, bed material, standpipe overflow, secondary cyclone underflow and

baghouse dust. When the secondary cyclone is removed from the circuit, the number of samples will be reduced to four. In addition, samples of coal and limestone will be taken at the start of each test period.

Task 4: Chemical Analysis and Data Analysis

Product ash streams will be sampled every 4 hours. However, chemical analysis will only be performed on two sets per test. The ashes will be analyzed for the following:

- moisture
- ash
- total carbon
- organic carbon
- total sulphur
- total calcium
- $CaCO_3$
- CaO
- $Ca(OH)_2$
- $CaSO_4$

This data together with on-line analysis of flue gas will be used to calculate combustion efficiency, SO_2 capture and the level of calcium utilization.

The results will also be used to identify the impact of hydration and humidification on sulphur capture.

Task 5: Final Report

The test procedures used to obtain the experimental results will be given together with test conditions and results. The report will also contain conclusions regarding the effectiveness of hydration and humidification on sulphur capture. Recommendations for future work will also be given.

APPENDIX B

Raw Data, Chemical Analyses and Mass Balances

SULPHUR CAPTURE STUDY

TEST NO: 1
START : 23:30-09/03/90
FINISH: 03:30-12/03/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 2.0:1
SECONDARY CYCLONE: OFF

TEST NO: 1

FINAL RESULTS FOR MASS BALANCES		Avg	Std	Count	Min	Max
Bedsample	kg	1.69	0.21	13.00	1.35	2.00
Solids Feedrate	kg/hr	12.55	0.87	51.00	9.60	13.80
Secondary Cyclone Sample	kg	0.00	0.00	0.00	0.00	0.00
Secondary Cyclone Recycle	kg/hr	21.60	0.85	4.00	20.40	22.80
J-Valve Sample	kg	0.37	0.13	13.00	0.20	0.60
Baghouse Discharge	kg/hr	2.42	0.67	51.00	1.10	4.50
Standpipe Discharge	kg/hr	1.29	2.32	15.00	0.05	8.70
Total Flow Differential	in. H2O	22.61	0.57	52.00	21.50	24.00
Total Flow Pressure	psig	16.00	0.00	52.00	16.00	16.00
Total Flow Feedrate	kg/hr	101.15	1.28	52.00	98.66	104.23
Weepage	kg	0.00	0.00	0.00	0.00	0.00
Combustor Top Temp.	C	861.88	17.82	52.00	811.00	896.00
CO2 Concentration	%	15.83	1.46	51.00	11.20	18.40
O2 Concentration	%	3.23	1.05	50.00	1.80	6.80
CO Concentration	ppm	534.73	139.52	49.00	317.00	959.00
SO2 Concentration	ppm	1526.53	169.89	49.00	1150.00	1800.00
NOx Concentration	ppm	231.02	24.60	49.00	160.00	280.00

TEST NO: 1

OVERALL MASS BALANCE

Air Feedrate	kg/h	101.15
Nitrogen Feed Rate	kg/h	77.93
Mass flowrate of dry flue gas	kg/h	104.47
Mass flowrate of wet flue gas	kg/h	108.40
Total Input Streams	kg/h	113.70
Total Output Streams	kg/h	112.77
Overall Mass Balance Error	%	0.82
Theoretical Air Required	kg/h	87.96
Excess Air	%	15.00

CARBON BALANCE

Organic Carbon Input	kg/h	6.29
Inorganic Carbon Input	kg/h	0.44
Organic Carbon Out in Solids	kg/h	0.47
Inorganic Carbon Out in Solids	kg/h	0.04
Carbon Out in Flue Gas	kg/h	6.48
Carbon Balance Error	%	-3.89
Carbon Utilization (Solid Basis)	%	92.98
Carbon Utilization (Gas Basis)	%	96.85

SULPHUR BALANCE

Sulphur Input	kg/h	0.58
Sulphur Out in Solids	kg/h	0.39
Sulphur Out in Flue Gas	kg/h	0.17
Sulphur Balance Error	%	4.18
Sulphur Capture	%	71.59

CALCIUM BALANCE

Calcium Input	kg/h	1.46
Calcium Out in Solids	kg/h	1.21
Ca/S Ratio		2.00
Calcium Balance Error	%	17.28

ASH BALANCE

Ash Input	kg/h	3.31
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	1.05
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	0.99
Total Ash Input (Gas Basis)	kg/h	4.36
Total Ash Input (Solids Basis)	kg/h	4.30
Total Ash Out	kg/h	3.66
Ash Balance Error (Gas Basis)	%	16.06
Ash Balance Error (Solids Basis)	%	14.86

TEST NO: 1

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 2.00

S : 1.00

INPUT STREAMS

SPECIES		COAL	LIMESTONE
H2O	%	2.99	0.00
Ash	%	13.78	56.56
Total Carbon	%	71.00	11.85
Organic Carbon	%	71.00	0.00
Inorganic Carbon	%	0.00	11.85
Sulphur	%	6.60	0.00
Calcium	%	0.00	39.57
Hydrogen	%	4.60	0.00
Nitrogen	%	1.22	0.00
Oxygen	%	2.80	47.38
MASS OF COAL	kg	100.00	
MASS OF LIMESTONE	kg		41.71
Total Flow	kg/h	8.86	3.69

FLUE GAS ANALYSIS

CO2	%	15.83
O2	%	3.23
CO	ppm	534.73
SO2	ppm	1526.53
NOx	ppm	231.02
N2	%	80.71
MOLE wt. of flue gas		30.73

TEST NO: 1

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		05:30-10/3	01:30-12/3	AVG.	STD
		3	13		
Bedsample					
Ash	%	99.23	99.58	99.41	0.17
Total Carbon	%	0.16	0.01	0.09	0.08
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.16	0.01	0.09	0.08
Total Sulphur	%	15.23	16.59	15.91	0.68
Sulphate Sulphur	%				
Total Calcium	%	32.91	36.23	34.57	1.66
Total Flow	kg/h			0.43	
J - Valve					
Ash	%	99.19	99.44	99.32	0.13
Total Carbon	%	0.14	0.17	0.16	0.02
Organic Carbon	%	0.05	0.00	0.03	0.03
Inorganic Carbon	%	0.09	0.17	0.13	0.04
Total Sulphur	%	14.79	15.96	15.38	0.59
Sulphate Sulphur	%	0.00			
Total Calcium	%	31.56	34.72	33.14	1.58
Total Flow	kg/h			0.09	
Baghouse + Cyclone Discharge					
Ash	%	80.46	82.00	81.23	0.77
Total Carbon	%	8.92	16.50	12.71	3.79
Organic Carbon	%	7.50	15.17	11.34	3.84
Inorganic Carbon	%	1.42	1.33	1.38	0.04
Total Sulphur	%	7.36	8.65	8.01	0.65
Sulphate Sulphur	%				
Total Calcium	%	25.22	28.26	26.74	1.52
Total Flow	kg/h			2.56	
Standpipe					
Ash	%	82.14	82.57	82.36	0.21
Total Carbon	%	14.23	14.16	14.20	0.04
Organic Carbon	%	14.23	14.08	14.16	0.08
Inorganic Carbon	%	0.00	0.08	0.04	0.04
Total Sulphur	%	7.60	8.99	8.30	0.70
Sulphate Sulphur	%				
Total Calcium	%	26.32	27.42	26.87	0.55
Total Flow	kg/h			1.29	

No Weepage And Secondary Cyclone

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO. 1
DATE: MAR. 9-12 /90

TIME:		23.30	0.30	1.30	2.30	3.30	4.30	5.30	6.30	7.30
Bedsample	kg			2.00				1.80		
Solids Feedrate	kg/hr	13.20	13.20	13.00	13.00	12.60	12.80	12.40	12.20	11.60
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr									
J-Valve Sample	kg			0.40				0.50		
Baghouse Discharge	kg/hr	4.00	3.40	3.30	2.90	3.00	3.00	2.70	2.70	2.50
Standpipe Discharge	kg/hr	8.70		0.10				0.10		
Primary Air Differential	in. H20	30.00	30.00	32.00	30.00	30.00	30.00	31.00	30.00	30.00
Primary Air Pressure	psig	3.00	3.20	3.00	3.20	3.20	3.20	3.00	3.20	3.00
Primary Air Feedrate	kg/hr	59.41	59.74	61.35	59.74	59.74	59.74	60.39	59.74	59.41
Total Flow Differential	in. H20	22.50	23.00	22.50	22.50	22.50	22.50	22.50	23.00	22.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	100.92	102.04	100.92	100.92	100.92	100.92	100.92	102.04	99.80
Rotameter 1 % Flow	%	40.00	40.00	40.00	40.00	40.00	40.00	40.00	42.00	40.00
Rotameter 1 Pressure	psig	2.20	2.00	2.00	2.20	2.80	2.00	2.20	2.60	2.50
Rotameter 1 Flow	kg/hr	5.74	5.70	5.70	5.74	5.84	5.70	5.74	6.09	5.79
Rotameter 2 % Flow	%	75.00	75.00	75.00	75.00	75.00	75.00	70.00	75.00	70.00
Rotameter 2 Pressure	psig	3.80	4.00	4.00	3.50	3.10	4.00	4.50	4.00	4.50
Rotameter 2 Flow	kg/hr	11.26	11.32	11.32	11.16	11.04	11.32	10.70	11.32	10.70
Rotameter 3 % Flow	%	50.00	50.00	50.00	50.00	45.00	50.00	50.00	50.00	50.00
Rotameter 3 Pressure	psig	2.80	3.00	3.00	2.50	3.00	2.00	2.00	2.00	2.50
Rotameter 3 Flow	kg/hr	7.30	7.34	7.34	7.23	6.61	7.13	7.13	7.13	7.23
Rotameter 4 % Flow	%	60.00	62.00	62.00	62.00	60.00	60.00	60.00	60.00	60.00
Rotameter 4 Pressure	psig	2.80	2.50	2.50	2.50	2.60	3.00	2.50	2.80	3.00
Rotameter 4 Flow	kg/hr	8.76	8.97	8.97	8.97	8.71	8.81	8.68	8.76	8.81
Sum Rotameters 1 to 5	kg/hr	33.05	33.33	33.33	33.11	32.19	32.96	32.25	33.30	32.53
Rotameters Total Flow Diff.	in.H20	16.00	15.00	15.00	16.00	16.00	15.00	15.00	15.00	16.00
Rotameters Total Flow P	psig	12.60	12.60	12.60	12.60	12.40	12.50	12.40	12.40	12.60
Rotameters Total Flow	kg/hr	33.73	32.66	32.66	33.73	33.61	32.60	32.54	32.54	33.73
Sum Total Flow	kg/hr	93.14	92.40	94.02	93.47	93.35	92.34	92.93	92.28	93.14
Combustor Bottom Temp.	C	866.00	843.00	839.00	855.00	843.00	829.00	825.00	833.00	856.00
Combustor Middle Temp.	C	878.00	857.00	853.00	869.00	857.00	843.00	839.00	846.00	869.00
Combustor Top Temp.	C	875.00	857.00	852.00	868.00	857.00	842.00	839.00	846.00	868.00
Standpipe Top Temp.	C	814.00	815.00	811.00	811.00	813.00	806.00	803.00	804.00	808.00
Standpipe Middle Temp.	C	679.00	643.00	641.00	679.00	633.00	612.00	612.00	623.00	666.00
Standpipe Bottom Temp.	C	672.00	635.00	633.00	671.00	625.00	604.00	604.00	614.00	657.00
CO2 Concentration	%	13.80	14.70	15.40	16.10	15.40	15.10	14.90	15.20	15.50
O2 Concentration	%	3.90	3.40	3.80	3.20	3.70	3.70	3.80	3.40	3.00
CO Concentration	ppm	354.00	371.00	345.00	398.00	357.00	429.00	445.00	497.00	487.00
SO2 Concentration	ppm	1300.00	1250.00	1250.00	1300.00	1150.00	1200.00	1400.00	1500.00	1650.00
NOx Concentration	ppm	260.00	260.00	260.00	260.00	240.00	220.00	220.00	220.00	240.00

TEST NO: 1

DATE: MAR. 9-12 /90

TIME:		8.30	9.30	10.30	11.30	12.30	13.30	14.30	15.30	16.30
Bedsample	kg		1.50				1.40			
Solids Feedrate	kg/hr	12.60	11.40			13.20	11.00	12.20	10.80	12.60
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr									
J-Valve Sample	kg		0.25				0.20			
Baghouse Discharge	kg/hr	4.50	2.00		2.10	3.10	1.70	3.10	2.00	
Standpipe Discharge	kg/hr		0.20				0.05			
Primary Air Differential	in. H2O	30.00	30.00		30.00	30.00	30.00	30.00	30.00	31.00
Primary Air Pressure	psig	3.50	3.20		3.50	3.00	3.20	3.00	3.20	3.00
Primary Air Feedrate	kg/hr	60.24	59.74		60.24	59.41	59.74	59.41	59.74	60.39
Total Flow Differential	in. H2O	22.00	22.00		21.50	23.00	22.00	22.00	22.00	22.00
Total Flow Pressure	psig	16.00	16.00		16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	99.80	99.80		98.66	102.04	99.80	99.80	99.80	99.80
Rotameter 1 % Flow	%	41.00	40.00		40.00	42.00	40.00	40.00	40.00	40.00
Rotameter 1 Pressure	psig	2.20	2.50		2.40	2.00	2.00	1.50	2.50	2.00
Rotameter 1 Flow	kg/hr	5.88	5.79		5.77	5.99	5.70	5.62	5.79	5.70
Rotameter 2 % Flow	%	76.00	70.00		70.00	70.00	65.00	70.00	71.00	70.00
Rotameter 2 Pressure	psig	2.90	4.00		4.50	4.00	4.00	2.00	2.20	2.00
Rotameter 2 Flow	kg/hr	11.12	10.56		10.70	10.56	9.81	9.98	10.18	9.98
Rotameter 3 % Flow	%	49.00	50.00		50.00	50.00	45.00	55.00	50.00	50.00
Rotameter 3 Pressure	psig	3.20	3.20		3.30	3.00	3.50	2.00	2.00	2.50
Rotameter 3 Flow	kg/hr	7.23	7.38		7.40	7.34	6.70	7.84	7.13	7.23
Rotameter 4 % Flow	%	58.00	60.00		60.00	61.00	61.00	60.00	60.00	60.00
Rotameter 4 Pressure	psig	3.00	3.00		3.00	2.70	2.70	2.30	2.40	2.40
Rotameter 4 Flow	kg/hr	8.51	8.81		8.81	8.88	8.88	8.63	8.66	8.66
Sum Rotameters 1 to 5	kg/hr	32.75	32.54		32.68	32.77	31.09	32.07	31.76	31.58
Rotameters Total Flow Diff.	in.H2O	16.00	15.00		15.00	15.00	15.00	14.00	14.00	15.00
Rotameters Total Flow P	psig	12.80	12.60		13.00	13.00	12.80	13.00	13.00	13.00
Rotameters Total Flow	kg/hr	33.86	32.66		32.90	32.90	32.78	31.78	31.78	32.90
Sum Total Flow	kg/hr	94.09	92.40		93.14	92.31	92.52	91.19	91.52	93.29
Combustor Bottom Temp.	C	850.00	821.00		821.00	864.00	868.00	848.00	822.00	880.00
Combustor Middle Temp.	C	864.00	836.00		832.00	877.00	882.00	862.00	835.00	894.00
Combustor Top Temp.	C	864.00	836.00		828.00	873.00	880.00	861.00	833.00	896.00
Standpipe Top Temp.	C	814.00	807.00		699.00	775.00	788.00	796.00	779.00	805.00
Standpipe Middle Temp.	C	629.00	612.00		646.00	733.00	689.00	597.00	666.00	740.00
Standpipe Bottom Temp.	C	621.00	603.00		637.00	724.00	681.00	589.00	654.00	729.00
CO2 Concentration	%	11.20	14.00		17.70	16.00	14.10	14.80	14.00	15.90
O2 Concentration	%		5.00		1.80	2.80	4.50	3.70	4.50	2.90
CO Concentration	ppm		566.00			757.00	317.00	672.00	477.00	691.00
SO2 Concentration	ppm		1550.00			1500.00	1650.00	1600.00	1150.00	1600.00
NOx Concentration	ppm		180.00			260.00	260.00	220.00	260.00	260.00

TEST NO: 1

DATE: MAR. 9-12 /90

TIME:		17.30	18.30	19.30	20.30	21.30	22.30	23.30	0.30	1.30
Bedsample	kg	1.35				2.00				1.80
Solids Feedrate	kg/hr	12.40	11.40	11.20	13.40	13.60	13.00	13.00	13.20	13.20
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr									21.60
J-Valve Sample	kg	0.25				0.50				0.50
Baghouse Discharge	kg/hr	2.80	2.30	2.20	1.40	1.90	2.10	2.20	2.30	2.30
Standpipe Discharge	kg/hr	0.25				0.20				0.20
Primary Air Differential	in. H2O	30.00	30.00	33.00	33.00	34.00	32.00	32.00	32.00	32.00
Primary Air Pressure	psig	3.00	3.20	3.20	3.00	3.40	3.20	3.40	3.20	3.40
Primary Air Feedrate	kg/hr	59.41	59.74	62.66	62.31	63.95	61.70	62.04	61.70	62.04
Total Flow Differential	in. H2O	22.00	22.00	22.00	22.50	23.00	23.00	23.00	23.00	23.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	99.80	99.80	99.80	100.92	102.04	102.04	102.04	102.04	102.04
Rotameter 1 % Flow	%	40.00	42.00	40.00	40.00	42.00	42.00	42.00	40.00	42.00
Rotameter 1 Pressure	psig	1.50	2.00	2.50	2.00	2.00	2.00	2.00	2.50	2.10
Rotameter 1 Flow	kg/hr	5.62	5.99	5.79	5.70	5.99	5.99	5.99	5.79	6.01
Rotameter 2 % Flow	%	65.00	68.00	68.00	68.00	73.00	75.00	70.00	68.00	65.00
Rotameter 2 Pressure	psig	4.00	3.50	3.50	3.50	2.00	2.50		3.50	4.00
Rotameter 2 Flow	kg/hr	9.81	10.12	10.12	10.12	10.41	10.85		10.12	9.81
Rotameter 3 % Flow	%	45.00	45.00	45.00	45.00	47.00	45.00	45.00	45.00	45.00
Rotameter 3 Pressure	psig	3.50	2.00	3.00	2.50	2.00	2.50	2.50	3.00	3.00
Rotameter 3 Flow	kg/hr	6.70	6.42	6.61	6.51	6.70	6.51	6.51	6.61	6.61
Rotameter 4 % Flow	%	62.00	60.00	60.00	60.00	61.00	61.00	62.00	60.00	62.00
Rotameter 4 Pressure	psig	2.50	2.40	3.20	2.80	3.00	3.00	2.50	2.80	2.60
Rotameter 4 Flow	kg/hr	8.97	8.66	8.86	8.76	8.95	8.95	8.97	8.76	9.00
Sum Rotameters 1 to 5	kg/hr	31.09	31.18	31.37	31.09	32.05	32.31	21.47	31.27	31.42
Rotameters Total Flow Diff.	in.H2O	14.00	14.00	14.00	14.50	14.00	14.00	14.00	14.50	15.00
Rotameters Total Flow P	psig	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00
Rotameters Total Flow	kg/hr	31.78	31.78	31.78	32.35	31.78	31.78	31.78	32.35	32.90
Sum Total Flow	kg/hr	91.19	91.52	94.44	94.65	95.74	93.48	93.83	94.05	94.94
Combustor Bottom Temp.	C	863.00	852.00	841.00	845.00	853.00	853.00	856.00	848.00	852.00
Combustor Middle Temp.	C	878.00	867.00	855.00	861.00	868.00	869.00	871.00	863.00	867.00
Combustor Top Temp.	C	868.00	866.00	854.00	860.00	867.00	868.00	870.00	862.00	866.00
Standpipe Top Temp.	C	815.00	810.00	805.00	808.00	811.00	814.00	814.00	811.00	812.00
Standpipe Middle Temp.	C	687.00	673.00	664.00	662.00	684.00	684.00	675.00	675.00	682.00
Standpipe Bottom Temp.	C	677.00	665.00	655.00	653.00	676.00	676.00	666.00	667.00	674.00
CO2 Concentration	%	14.50		14.60	17.60	17.60	17.40	17.70	18.20	18.40
O2 Concentration	%	3.70		3.80	2.50	2.40	2.40	2.20	2.20	2.20
CO Concentration	ppm	407.00		357.00	609.00	560.00	547.00	655.00	690.00	704.00
SO2 Concentration	ppm	1500.00		1450.00	1700.00	1500.00	1800.00	1800.00	1700.00	1600.00
NOx Concentration	ppm	280.00		200.00	220.00	220.00	220.00	220.00	220.00	220.00

TEST NO:	1									
DATE:	MAR. 9-12 /90									
TIME:		2.30	3.30	4.30	5.30	6.30	7.30	8.30	9.30	10.30
Bedsample	kg				1.70				1.50	
Solids Feedrate	kg/hr	13.60	13.00	12.60	12.40	12.00	13.00	13.40	12.60	12.80
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr				20.40					
J-Valve Sample	kg				0.40				0.30	
Baghouse Discharge	kg/hr	2.20	2.30	2.30	2.30	2.50	2.20	4.30	2.00	2.50
Standpipe Discharge	kg/hr				0.30				1.00	
Primary Air Differential	in. H20	32.00	32.00	32.00	30.00	32.00	33.00	33.00	35.00	29.00
Primary Air Pressure	psig	3.20	3.20	3.40	3.80	3.50	3.80	3.00	3.20	3.20
Primary Air Feedrate	kg/hr	61.70	61.70	62.04	60.73	62.21	63.70	62.31	64.53	58.74
Total Flow Differential	in. H20	23.00	22.50	22.50	22.00	22.50	24.00	24.00	24.00	22.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	102.04	100.92	100.92	99.80	100.92	104.23	104.23	104.23	99.80
Rotameter 1 % Flow	%	45.00	42.00	42.00		40.00	40.00	40.00	42.00	44.00
Rotameter 1 Pressure	psig	2.80	2.50	1.80		2.80	2.50	2.30	1.50	2.00
Rotameter 1 Flow	kg/hr	6.57	6.08	5.95		5.84	5.79	5.75	5.90	6.27
Rotameter 2 % Flow	%	68.00	68.00	74.00		65.00	65.00	65.00	75.00	75.00
Rotameter 2 Pressure	psig	3.50	3.30	2.50		4.00	4.50	4.50	2.00	2.50
Rotameter 2 Flow	kg/hr	10.12	10.07	10.71		9.81	9.94	9.94	10.69	10.85
Rotameter 3 % Flow	%	45.00	45.00	45.00		45.00	45.00	40.00	45.00	45.00
Rotameter 3 Pressure	psig	3.00	2.80	2.30		3.00	3.00	3.00	3.00	2.30
Rotameter 3 Flow	kg/hr	6.61	6.57	6.47		6.61	6.61	5.87	6.61	6.47
Rotameter 4 % Flow	%	62.00	62.00	60.00		60.00	62.00	60.00	63.00	60.00
Rotameter 4 Pressure	psig	2.80	2.80	3.10		3.30	3.40	3.40	4.00	2.90
Rotameter 4 Flow	kg/hr	9.05	9.05	8.83		8.88	9.20	8.91	9.51	8.78
Sum Rotameters 1 to 5	kg/hr	32.34	31.76	31.97		31.13	31.53	30.47	32.70	32.38
Rotameters Total Flow Diff.	in.H20	15.50	15.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Rotameters Total Flow P	psig	12.60	12.60	13.00	13.00	13.00	12.80	12.80	12.80	13.00
Rotameters Total Flow	kg/hr	33.20	32.66	31.78	31.78	31.78	31.67	31.67	31.67	31.78
Sum Total Flow	kg/hr	94.90	94.36	93.83	92.52	94.00	95.37	93.97	96.20	90.52
Combustor Bottom Temp.	C	857.00	850.00	847.00	837.00	804.00	809.00	852.00	859.00	857.00
Combustor Middle Temp.	C	872.00	865.00	862.00	851.00	819.00	823.00	866.00	874.00	871.00
Combustor Top Temp.	C	871.00	864.00	860.00	850.00	818.00	822.00	865.00	873.00	869.00
Standpipe Top Temp.	C	815.00	814.00	811.00	805.00	791.00	785.00	805.00	812.00	807.00
Standpipe Middle Temp.	C	690.00	686.00	684.00	664.00	652.00	642.00	734.00	732.00	678.00
Standpipe Bottom Temp.	C	682.00	678.00	676.00	656.00	644.00	634.00	725.00	723.00	670.00
CO2 Concentration	%	18.30	17.10	16.80	16.10	13.30	15.50	16.40	16.00	16.40
O2 Concentration	%	2.30	2.80	2.60	3.10	6.40	3.50	3.10	3.30	2.50
CO Concentration	ppm	959.00	596.00	722.00	686.00	571.00	662.00	613.00	395.00	728.00
SO2 Concentration	ppm	1700.00	1500.00	1500.00	1500.00	1500.00	1800.00	1750.00	1500.00	1500.00
NOx Concentration	ppm	220.00	240.00	220.00	220.00	160.00	180.00	260.00	260.00	220.00

TEST NO: 1

DATE: MAR. 9-12 /90

TIME:		11.30	12.30	13.30	14.30	15.30	16.30	17.30	18.30	19.30
Bedsample	kg			1.55				1.65		
Solids Feedrate	kg/hr	10.60	11.60	12.60	12.40	11.60	12.40	13.80	13.60	13.00
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr									
J-Valve Sample	kg			0.20				0.25		
Baghouse Discharge	kg/hr	1.70	1.80	2.00	3.10	1.10	2.60	2.10	2.30	2.60
Standpipe Discharge	kg/hr			0.80				2.40		
Primary Air Differential	in. H2O	32.00	34.00	33.00	32.00	32.00	30.00	32.00	32.00	32.00
Primary Air Pressure	psig	3.80	3.80	3.20	4.00	3.00	4.00	3.50	3.00	3.50
Primary Air Feedrate	kg/hr	62.73	64.66	62.66	63.06	61.35	61.06	62.21	61.35	62.21
Total Flow Differential	in. H2O	23.00	22.50	23.00	22.00	23.00	23.00	23.00	22.00	22.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	102.04	100.92	102.04	99.80	102.04	102.04	102.04	99.80	99.80
Rotameter 1 % Flow	%	45.00	45.00	45.00	40.00	40.00	44.00	40.00	42.00	45.00
Rotameter 1 Pressure	psig	1.70	3.00	1.50	2.50	1.30	1.80	1.50	1.50	1.80
Rotameter 1 Flow	kg/hr	6.36	6.61	6.32	5.79	5.58	6.24	5.62	5.90	6.38
Rotameter 2 % Flow	%	65.00	50.00	70.00	60.00	65.00	69.00	65.00	55.00	65.00
Rotameter 2 Pressure	psig	4.50	5.00	1.70	4.20	3.20	2.20	3.00	4.50	2.50
Rotameter 2 Flow	kg/hr	9.94	7.74	9.89	9.10	9.59	9.90	9.54	8.41	9.41
Rotameter 3 % Flow	%	45.00	45.00	40.00	40.00	40.00	44.00	40.00	40.00	45.00
Rotameter 3 Pressure	psig	2.50	3.50	3.00	4.00	3.20	3.10	3.00	3.50	2.20
Rotameter 3 Flow	kg/hr	6.51	6.70	5.87	6.04	5.90	6.48	5.87	5.95	6.45
Rotameter 4 % Flow	%	63.00	63.00	65.00	64.00	70.00	66.00	65.00	65.00	65.00
Rotameter 4 Pressure	psig	3.30	3.40	2.80	3.30	3.00	3.20	3.20	3.30	3.00
Rotameter 4 Flow	kg/hr	9.33	9.35	9.49	9.47	10.28	9.74	9.59	9.62	9.54
Sum Rotameters 1 to 5	kg/hr	32.13	30.40	31.57	30.40	31.36	32.35	30.62	29.88	31.78
Rotameters Total Flow Diff.	in.H2O	15.00	14.00	13.50	13.50	14.00	14.00	14.00	13.50	14.00
Rotameters Total Flow P	psig	13.20	13.00	13.00	13.20	13.00	13.00	13.00	13.00	13.00
Rotameters Total Flow	kg/hr	33.02	31.78	31.21	31.32	31.78	31.78	31.78	31.21	31.78
Sum Total Flow	kg/hr	95.74	96.44	93.87	94.39	93.14	92.84	94.00	92.57	94.00
Combustor Bottom Temp.	C	797.00	837.00	853.00	854.00	843.00	843.00	857.00	857.00	861.00
Combustor Middle Temp.	C	812.00	851.00	869.00	869.00	858.00	857.00	872.00	872.00	876.00
Combustor Top Temp.	C	811.00	849.00	867.00	867.00	856.00	855.00	870.00	875.00	874.00
Standpipe Top Temp.	C	784.00	796.00	813.00	813.00	814.00	802.00	813.00	815.00	811.00
Standpipe Middle Temp.	C	654.00	737.00	720.00	724.00	737.00	718.00	711.00	702.00	700.00
Standpipe Bottom Temp.	C	645.00	726.00	711.00	716.00	727.00	710.00	703.00	694.00	696.00
CO2 Concentration	%	12.70	15.70	15.60	14.40	14.70	16.60	16.50	16.60	16.30
O2 Concentration	%	6.80	3.80	3.60	4.90	4.90	2.90	2.90	2.60	2.50
CO Concentration	ppm	529.00	457.00	421.00	443.00	397.00	612.00	493.00	611.00	834.00
SO2 Concentration	ppm	1575.00	1350.00	1375.00	1500.00	1500.00	1500.00	1650.00	1800.00	1600.00
NOx Concentration	ppm	180.00	240.00	260.00	200.00	220.00	220.00	240.00	240.00	220.00

TEST NO: 1

DATE: MAR. 9-12 /90

TIME:		20.30	21.30	22.30	23.30	0.30	1.30	2.30	3.30
Bedsample	kg						1.90		1.80
Solids Feedrate	kg/hr	12.80	12.40	9.60	13.20	13.80	12.80	13.40	13.00
Secondary Cyclone Sample	kg						22.80		21.60
Secondary Cyclone Discharge	kg/hr						0.40		0.60
J-Valve Sample	kg						2.10	2.40	2.10
Baghouse Discharge	kg/hr	1.20	2.20	1.60	2.00	2.30	0.20		0.10
Standpipe Discharge	kg/hr		4.70				33.00	33.00	33.00
Primary Air Differential	in. H20	32.00	32.00	34.00	35.00	32.00	3.10	3.20	3.00
Primary Air Pressure	psig	3.60	3.20	3.50	3.00	3.20	62.48	62.66	62.31
Primary Air Feedrate	kg/hr	62.39	61.70	64.13	64.17	61.70	23.00	23.00	23.00
Total Flow Differential	in. H20	22.00	22.00	23.50	23.00	23.00	16.00	16.00	16.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	102.04	102.04	102.04
Total Flow Feedrate	kg/hr	99.80	99.80	103.14	102.04	102.04	45.00	45.00	43.00
Rotameter 1 % Flow	%	45.00	45.00	42.00	45.00	45.00	1.30	1.30	1.70
Rotameter 1 Pressure	psig	2.00	2.00	1.80	1.20	1.20	6.28	6.28	6.08
Rotameter 1 Flow	kg/hr	6.42	6.42	5.95	6.26	6.26	65.00	65.00	65.00
Rotameter 2 % Flow	%	66.00	65.00	61.00	64.00	60.00	1.50	1.80	4.00
Rotameter 2 Pressure	psig	2.40	3.00	2.10	1.70	2.50	9.13	9.21	9.81
Rotameter 2 Flow	kg/hr	9.52	9.54	8.72	9.04	8.68	50.00	50.00	45.00
Rotameter 3 % Flow	%	45.00	45.00	46.00	50.00	50.00	1.60	2.00	2.50
Rotameter 3 Pressure	psig	3.00	2.00	2.30	1.80	1.50	7.04	7.13	6.51
Rotameter 3 Flow	kg/hr	6.61	6.42	6.62	7.09	7.02	71.00	70.00	72.00
Rotameter 4 % Flow	%	65.00	70.00	72.00	70.00	70.00	2.90	2.80	2.60
Rotameter 4 Pressure	psig	3.00	3.00	2.80	3.00	2.90	10.39	10.22	10.45
Rotameter 4 Flow	kg/hr	9.54	10.28	10.51	10.28	10.25	32.84	32.84	32.84
Sum Rotameters 1 to 5	kg/hr	32.08	32.65	31.80	32.66	32.21	14.00	14.00	14.00
Rotameters Total Flow Diff.	in.H20	14.50	15.00	14.00	14.00	14.00	12.80	12.80	12.80
Rotameters Total Flow P	psig	13.00	13.00	12.80	12.80	12.80	31.67	31.67	31.67
Rotameters Total Flow	kg/hr	32.35	32.90	31.67	31.67	31.67	94.15	94.33	93.97
Sum Total Flow	kg/hr	94.73	94.60	95.80	95.83	93.37	874.00	877.00	868.00
Combustor Bottom Temp.	C	858.00	857.00	863.00	868.00	868.00	890.00	894.00	885.00
Combustor Middle Temp.	C	874.00	873.00	879.00	885.00	885.00	888.00	891.00	882.00
Combustor Top Temp.	C	872.00	871.00	877.00	883.00	882.00	836.00	840.00	838.00
Standpipe Top Temp.	C	816.00	815.00	815.00	831.00	831.00	734.00	740.00	725.00
Standpipe Middle Temp.	C	696.00	695.00	762.00	734.00	724.00	726.00	732.00	717.00
Standpipe Bottom Temp.	C	689.00	687.00	754.00	728.00	717.00	17.10	17.20	16.30
CO2 Concentration	%	16.00	15.90	16.80	16.20	17.00	2.30	2.10	2.70
O2 Concentration	%	2.50	2.50	2.00	2.40	2.10	434.00	529.00	392.00
CO Concentration	ppm	485.00	528.00	448.00	454.00	511.00	1500.00	1500.00	1400.00
SO2 Concentration	ppm	1800.00	1500.00	1500.00	1800.00	1600.00	240.00	240.00	240.00
NOx Concentration	ppm	220.00	240.00	240.00	240.00	240.00			

SULPHUR CAPTURE STUDY

TEST NO: 2
START : 04:30-08/03/90
FINISH: 20:30-08/03/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 2.0:1
SECONDARY CYCLONE: ON

TEST NO: 2

FINAL RESULTS FOR MASS BALANCES:

		Avg	Std	Count	Min	Max
Bedsample	kg	1.36	0.68	4.00	0.20	1.85
Solids Feedrate	kg/hr	12.92	0.43	17.00	12.00	13.80
Cyclone Recycle Sample	kg	2.75	1.54	4.00	0.80	4.50
Secondary Cyclone Recycle	kg/hr	33.00	18.52	4.00	9.60	54.00
J-Valve Sample	kg	0.16	0.06	4.00	0.10	0.25
Baghouse Discharge	kg/hr	0.45	0.61	17.00	0.05	2.00
Standpipe Discharge	kg/hr	1.36	1.14	17.00	0.05	3.70
Total Flow Differential	in. H20	22.26	1.26	17.00	20.00	25.00
Total Flow Pressure	psig	16.00	0.00	17.00	16.00	16.00
Total Flow Feedrate	kg/hr	100.35	2.84	17.00	95.15	106.38
Weepage	kg	0.00	0.00	17.00	0.00	0.00
Combustor Top Temp.	C	868.24	18.79	17.00	841.00	920.00
CO2 Concentration	%	15.61	1.88	15.00	12.00	18.20
O2 Concentration	%	3.13	1.56	15.00	1.80	6.90
CO Concentration	ppm	178.80	144.19	15.00	56.00	510.00
SO2 Concentration	ppm	709.09	259.43	11.00	350.00	1200.00
NOx Concentration	ppm	253.33	37.00	15.00	180.00	300.00

TEST NO: 2

OVERALL MASS BALANCE

Air Feedrate	kg/h	100.35
Nitrogen Feed Rate	kg/h	77.32
Mass flowrate of dry flue gas	kg/h	102.74
Mass flowrate of wet flue gas	kg/h	106.79
Total Input Streams	kg/h	113.27
Total Output Streams	kg/h	109.61
Overall Mass Balance Error	%	3.23
Theoretical Air Required	kg/h	90.51
Excess Air	%	10.87

CARBON BALANCE

Organic Carbon Input	kg/h	6.47
Inorganic Carbon Input	kg/h	0.45
Organic Carbon Out in Solids	kg/h	0.08
Inorganic Carbon Out in Solids	kg/h	0.01
Carbon Out in Flue Gas	kg/h	6.29
Carbon Balance Error	%	7.86
Carbon Utilization (Solid Basis)	%	98.83
Carbon Utilization (Gas Basis)	%	90.96

SULPHUR BALANCE

Sulphur Input	kg/h	0.60
Sulphur Out in Solids	kg/h	0.34
Sulphur Out in Flue Gas	kg/h	0.08
Sulphur Balance Error	%	31.44
Sulphur Capture	%	87.36

CALCIUM BALANCE

Calcium Input	kg/h	1.50
Calcium Out in Solids	kg/h	0.84
Ca/S Ratio		2.00
Calcium Balance Error	%	44.27

ASH BALANCE

Ash Input	kg/h	3.41
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	1.31
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	0.84
Total Ash Input (Gas Basis)	kg/h	4.72
Total Ash Input (Solids Basis)	kg/h	4.25
Total Ash Out	kg/h	2.69
Ash Balance Error (Gas Basis)	%	42.92
Ash Balance Error (Solids Basis)	%	36.57

TEST NO: 2

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 2.00

S : 1.00

INPUT STREAMS

SPECIES		COAL	LIMESTONE
H2O	%	2.99	0.00
Ash	%	13.78	56.57
Total Carbon	%	71.00	11.85
Organic Carbon	%	71.00	0.00
Inorganic Carbon	%	0.00	11.85
Sulphur	%	6.60	0.00
Calcium	%	0.00	39.57
Hydrogen	%	4.60	0.00
Nitrogen	%	1.22	0.00
Oxygen	%	2.80	47.38
MASS OF COAL	kg	100.00	
MASS OF LIMESTONE	kg		41.71
Total Flow	kg/h	9.12	3.80

FLUE GAS ANALYSIS

CO2	%	15.61
O2	%	3.13
CO	ppm	178.80
SO2	ppm	709.09
NOx	ppm	253.33
N2	%	81.14
MOLE wt. of flue gas		30.66

TEST NO: 2

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		09:30 3	17:30 5	AVG.	STD.
Secondary Cyclone					
Ash	%	96.37	94.64	95.51	0.87
Total Carbon	%	2.85	4.71	3.78	0.93
Organic Carbon	%	2.56	4.20	3.38	0.82
Inorganic Carbon	%	0.29	0.51	0.40	0.11
Total Sulphur	%	11.82	12.02	11.92	0.10
Total Calcium	%	31.81	31.08	31.45	0.37
Total Flow	kg/h			0.65	
J - Valve					
Ash	%	99.40	96.57	97.99	1.42
Total Carbon	%	0.06	0.01	0.04	0.03
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.06	0.01	0.04	0.03
Total Sulphur	%	13.70	14.46	14.08	0.38
Total Calcium	%	31.06	30.88	30.97	0.09
Total Flow	kg/h			0.04	
Baghouse					
Ash	%	85.70	86.73	86.22	0.52
Total Carbon	%	10.27	10.01	10.14	0.13
Organic Carbon	%	8.69	9.66	9.18	0.49
Inorganic Carbon	%	1.58	0.35	0.96	0.62
Total Sulphur	%	7.17	7.98	7.58	0.41
Total Calcium	%	21.36	18.72	20.04	1.32
Total Flow	kg/h			0.45	
Standpipe					
Ash	%	98.65	96.29	97.47	1.18
Total Carbon	%	0.56	2.69	1.63	1.07
Organic Carbon	%	0.28	2.27	1.28	1.00
Inorganic Carbon	%	0.28	0.42	0.35	0.07
Total Sulphur	%	12.75	12.77	12.76	0.01
Total Calcium	%	31.31	31.81	31.56	0.25
Total Flow	kg/h			1.36	
No Weepage					
Bedsample					
Ash	%	99.49	99.15	99.32	0.17
Total Carbon	%	0.01	0.10	0.06	0.05
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.01	0.10	0.06	0.05
Total Sulphur	%	13.70	14.68	14.19	0.49
Total Calcium	%	31.06	32.30	31.68	0.62
Total Flow	kg/h			0.32	

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO: 2
DATE: MAR. 8 /90

TIME:		4.30	5.30	6.30	7.30	8.30	9.30	10.30	11.30	12.30
Bedsample	kg		1.80				1.85			
Solids Feedrate	kg/hr	13.00	13.20	13.00	13.00	12.60	13.00	13.40	13.80	12.00
Secondary Cyclone Sample	kg		1.70				4.50			
Secondary Cyclone Discharge	kg/hr		20.40				54.00			
J-Valve Sample	kg		0.20				0.25			
Baghouse Discharge	kg/hr	0.50	0.30	0.20	0.10	1.20	0.10	0.10	0.10	2.00
Standpipe Discharge	kg/hr	0.70	1.90	0.70	2.10	3.70	3.50	0.30	2.00	2.00
Primary Air Differential	in. H20	32.00	32.00	30.00	30.00	30.00	29.00	30.00	30.00	30.00
Primary Air Pressure	psig	3.00	3.00	3.00	3.00	3.00	3.00	3.20	3.30	3.10
Primary Air Feedrate	kg/hr	61.35	61.35	59.41	59.41	59.41	58.41	59.74	59.91	59.57
Total Flow Differential	in. H20	24.50	25.00	23.00	23.00	22.00	22.00	22.00	22.00	21.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	105.31	106.38	102.04	102.04	99.80	99.80	99.80	99.80	97.50
Rotameter 1 % Flow	%	30.00	30.00	32.00	32.00	35.00	35.00	35.00	36.00	40.00
Rotameter 1 Pressure	psig	2.00	2.00	1.50	2.00	2.50	2.20	2.00	2.50	2.00
Rotameter 1 Flow	kg/hr	4.28	4.28	4.49	4.56	5.06	5.02	4.99	5.21	5.70
Rotameter 2 % Flow	%	52.00	50.00	55.00	47.00	60.00	60.00	65.00	63.00	70.00
Rotameter 2 Pressure	psig	2.10	3.50	1.50	4.00	4.50	4.50	4.00	3.50	3.80
Rotameter 2 Flow	kg/hr	7.44	7.44	7.72	7.09	9.17	9.17	9.81	9.38	10.50
Rotameter 3 % Flow	%	57.00	50.00	50.00	50.00	35.00	35.00	36.00	35.00	38.00
Rotameter 3 Pressure	psig	2.50	4.00	3.50	3.50	3.50	3.00	3.10	3.00	3.00
Rotameter 3 Flow	kg/hr	8.25	7.54	7.44	7.44	5.21	5.14	5.30	5.14	5.58
Rotameter 4 % Flow	%	65.00	68.00	62.00	60.00	60.00	60.00	60.00	60.00	60.00
Rotameter 4 Pressure	psig	2.90	2.30	2.50	2.60	2.50	2.60	2.60	2.50	2.70
Rotameter 4 Flow	kg/hr	9.51	9.78	8.97	8.71	8.68	8.71	8.71	8.68	8.73
Rotameter 5 % Flow	%	60.00	60.00	50.00	50.00	50.00	50.00	50.00	50.00	
Rotameter 5 Pressure	psig	3.00	2.60	3.00	3.40	3.40	3.20	3.20	3.00	
Rotameter 5 Flow	kg/hr	8.81	8.71	7.34	7.42	7.42	7.38	7.38	7.34	
Sum Rotameters 1 to 5	kg/hr	38.28	37.75	35.97	35.22	35.55	35.42	36.18	35.75	30.52
Rotameters Total Flow Diff.	in.H20	22.00	21.50	18.00	18.00	19.00	19.00	18.50	18.50	14.00
Rotameters Total Flow P	psig	12.40	12.30	12.70	12.60	12.80	12.60	12.40	12.40	12.80
Rotameters Total Flow	kg/hr	39.41	38.89	35.84	35.78	36.89	36.76	36.14	36.14	31.67
Sum Total Flow	kg/hr	100.76	100.24	95.25	95.18	96.30	95.17	95.88	96.05	91.24
Combustor Bottom Temp.	C	869.00	847.00	839.00	841.00	831.00	832.00	840.00	822.00	854.00
Combustor Middle Temp.	C	874.00	855.00	846.00	845.00	838.00	837.00	849.00	831.00	854.00
Combustor Top Temp.	C	887.00	865.00	857.00	858.00	849.00	850.00	859.00	841.00	871.00
Standpipe Top Temp.	C	832.00	825.00	819.00	824.00	819.00	831.00	828.00	829.00	834.00
Standpipe Middle Temp.	C	743.00	755.00	743.00	799.00	788.00	823.00	764.00	828.00	832.00
Standpipe Bottom Temp.	C	733.00	747.00	736.00	792.00	783.00	817.00	759.00	822.00	827.00
CO2 Concentration	%	17.20	17.50	17.10	18.20	17.20	16.00	12.80	15.40	16.10
O2 Concentration	%	2.50	2.40	2.40	2.00	2.20	2.30	5.40	2.90	2.50
CO Concentration	ppm	239.00	288.00	289.00	510.00	342.00	344.00	216.00	57.00	57.00
SO2 Concentration	ppm	1000.00	650.00	700.00	600.00	475.00	350.00	650.00		
NOx Concentration	ppm	280.00	280.00	260.00	280.00	300.00	300.00	200.00	300.00	260.00

TEST NO: 2

DATE: MAR. 8 /90

TIME:		13.30	14.30	15.30	16.30	17.30	18.30	19.30	20.30
Bedsample	kg	1.60				0.20			
Solids Feedrate	kg/hr	13.20	12.50	13.00	12.50	13.40	13.00	12.60	12.40
Secondary Cyclone Sample	kg	0.80				4.00			
Secondary Cyclone Discharge	kg/hr	9.60				48.00			
J-Valve Sample	kg	0.10				0.10			
Baghouse Discharge	kg/hr	1.90	0.20	0.25	0.05	0.30	0.20	0.10	0.10
Standpipe Discharge	kg/hr	0.05	0.10	0.20	0.10	1.20	0.75	2.70	1.20
Primary Air Differential	in. H2O	30.00	28.00	29.00	30.00	30.00	28.00		30.00
Primary Air Pressure	psig	2.80	3.20	2.80	3.00	3.10	2.80		3.20
Primary Air Feedrate	kg/hr	59.07	57.71	58.08	59.41	59.57	57.07		59.74
Total Flow Differential	in. H2O	20.00	23.00	22.00	22.00	22.00	22.00	23.00	20.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	95.15	102.04	99.80	99.80	99.80	99.80	102.04	95.15
Rotameter 1 % Flow	%	37.00	35.00	35.00	33.00	35.00	35.00	38.00	40.00
Rotameter 1 Pressure	psig	2.00	2.00	2.00	2.20	2.00	1.70	2.00	2.00
Rotameter 1 Flow	kg/hr	5.28	4.99	4.99	4.73	4.99	4.95	5.42	5.70
Rotameter 2 % Flow	%	73.00	70.00	55.00	60.00	63.00	60.00	60.00	63.00
Rotameter 2 Pressure	psig	3.90	4.00	4.50	4.00	4.40	4.50	4.00	4.00
Rotameter 2 Flow	kg/hr	10.98	10.56	8.41	9.05	9.61	9.17	9.05	9.51
Rotameter 3 % Flow	%	40.00	40.00	35.00	30.00	32.00	35.00	35.00	39.00
Rotameter 3 Pressure	psig	3.00	3.00	5.50	3.50	3.00	3.50	3.00	2.80
Rotameter 3 Flow	kg/hr	5.87	5.87	5.49	4.47	4.70	5.21	5.14	5.69
Rotameter 4 % Flow	%	63.00	60.00	63.00	63.00	60.00	62.00	63.00	64.00
Rotameter 4 Pressure	psig	2.40	2.60	2.50	2.70	2.40	2.50	2.40	2.60
Rotameter 4 Flow	kg/hr	9.09	8.71	9.12	9.17	8.66	8.97	9.09	9.29
Rotameter 5 % Flow	%		60.00	60.00	60.00	60.00	62.00	60.00	64.00
Rotameter 5 Pressure	psig		2.60	2.60	3.80	3.60	3.80	4.00	3.10
Rotameter 5 Flow	kg/hr		8.71	8.71	9.00	8.96	9.30	9.05	9.42
Sum Rotameters 1 to 5	kg/hr	31.22	38.84	36.71	36.42	36.91	37.60	37.75	39.61
Rotameters Total Flow Diff.	in.H2O	14.00	20.00	18.00	19.00	18.00	20.00	20.00	20.00
Rotameters Total Flow P	psig	13.00	13.00	12.80	12.60	12.60	12.80	12.60	12.50
Rotameters Total Flow	kg/hr	31.78	37.99	35.91	36.76	35.78	37.85	37.71	37.64
Sum Total Flow	kg/hr	90.85	95.70	93.99	96.16	95.35	94.92	37.71	97.39
Combustor Bottom Temp.	C	902.00	868.00	862.00	853.00	829.00	846.00	849.00	869.00
Combustor Middle Temp.	C	899.00	871.00	863.00	859.00	837.00	851.00	852.00	869.00
Combustor Top Temp.	C	920.00	885.00	879.00	872.00	848.00	864.00	868.00	887.00
Standpipe Top Temp.	C	836.00	846.00	838.00	835.00	825.00	829.00	840.00	849.00
Standpipe Middle Temp.	C	724.00	719.00	799.00	787.00	788.00	769.00	833.00	849.00
Standpipe Bottom Temp.	C	726.00	711.00	793.00	783.00	785.00	765.00	830.00	846.00
CO2 Concentration	%	15.10	12.00	16.40	16.20	14.90	12.10		
O2 Concentration	%	2.60	6.90	1.90	1.80	3.10	6.10		
CO Concentration	ppm	57.00	56.00	56.00	57.00	57.00	57.00		
SO2 Concentration	ppm			1200.00	1100.00	525.00	550.00		
NOx Concentration	ppm	220.00	220.00	260.00	240.00	220.00	180.00		

SULPHUR CAPTURE STUDY

TEST NO: 3
START : 05:30-07/03/90
FINISH: 21.30-07/03/90
LIMESTONE TYPE: HYDRATED
Ca/S RATIO: 2:1
SECONDARY CYCLONE: OFF

TEST NO: 3

FINAL RESULTS FOR MASS BALANCES:		Avg	Std	Count	Min	Max
Solids Feedrate	kg/hr	10.99	1.23	17.00	9.00	13.60
Bedsample	kg	1.34	0.17	4.00	1.10	1.50
Secondary Cyclone Recycle	kg/hr	16.05	2.05	4.00	13.20	18.00
J-Valve Sample	kg	0.32	0.06	3.00	0.25	0.40
Baghouse Discharge	kg/hr	1.98	0.95	17.00	0.30	4.00
Standpipe Discharge	kg/hr	0.11	0.09	16.00	0.00	0.40
Total Flow Differential	in. H20	22.32	0.62	17.00	22.00	24.00
Total Flow Pressure	psig	16.00	0.00	17.00	16.00	16.00
Total Flow Feedrate	kg/hr	100.52	1.37	17.00	99.80	104.23
Weepage	kg	0.00	0.00	17.00	0.00	0.00
Combustor Top Temp.	C	884.41	21.78	17.00	854.00	922.00
CO2 Concentration	%	14.60	1.76	16.00	9.00	17.00
O2 Concentration	%	3.59	1.07	14.00	1.10	5.50
CO Concentration	ppm	504.56	295.27	16.00	143.00	1117.00
SO2 Concentration	ppm	794.29	496.90	14.00	300.00	2000.00
NOx Concentration	ppm	240.00	45.83	16.00	160.00	320.00

TEST NO: 3

OVERALL MASS BALANCE

Air Feedrate	kg/h	100.52
Nitrogen Feed Rate	kg/h	77.44
Mass flowrate of dry flue gas	kg/h	101.86
Mass flowrate of wet flue gas	kg/h	105.60
Total Input Streams	kg/h	111.51
Total Output Streams	kg/h	108.38
Overall Mass Balance Error	%	2.81
Theoretical Air Required	kg/h	83.59
Excess Air	%	20.26

CARBON BALANCE

Organic Carbon Input	kg/h	5.98
Inorganic Carbon Input	kg/h	0.00
Organic Carbon Out in Solids	kg/h	0.28
Inorganic Carbon Out in Solids	kg/h	0.02
Carbon Out in Flue Gas	kg/h	5.87
Carbon Balance Error	%	-3.22
Carbon Utilization (Solid Basis)	%	95.36
Carbon Utilization (Gas Basis)	%	98.57

SULPHUR BALANCE

Sulphur Input	kg/h	0.56
Sulphur Out in Solids	kg/h	0.26
Sulphur Out in Flue Gas	kg/h	0.08
Sulphur Balance Error	%	38.81
Sulphur Capture	%	84.73

CALCIUM BALANCE

Calcium Input	kg/h	1.39
Calcium Out in Solids	kg/h	0.68
Ca/S Ratio		2.00
Calcium Balance Error	%	51.05

ASH BALANCE

Ash Input	kg/h	3.10
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	1.18
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	0.64
Total Ash Input (Gas Basis)	kg/h	4.28
Total Ash Input (Solids Basis)	kg/h	3.74
Total Ash Out	kg/h	2.42
Ash Balance Error (Gas Basis)	%	43.37
Ash Balance Error (Solids Basis)	%	35.21

TEST NO: 3

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 2.00

S : 1.00

INPUT STREAMS

SPECIES		COAL	LIMESTONE
H2O	%	2.99	0.00
Ash	%	13.78	75.67
Total Carbon	%	71.00	0.00
Organic Carbon	%	71.00	0.00
Inorganic Carbon	%	0.00	0.00
Sulphur	%	6.60	0.00
Calcium	%	0.00	54.05
Hydrogen	%	4.60	2.70
Nitrogen	%	1.22	0.00
Oxygen	%	2.80	43.24
MASS OF COAL	kg	100.00	
MASS OF LIMESTONE	kg		30.53
Total Flow	kg/h	8.42	2.57

FLUE GAS ANALYSIS

CO2	%	14.60
O2	%	3.59
CO	ppm	504.56
SO2	ppm	794.29
NOx	ppm	240.00
N2	%	81.66
MOLE wt. of flue gas		30.52

TEST NO: 3

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		10:30 2	18:30 4	AVG.	STD.
Bedsample					
Ash	%	99.52	99.28	99.40	0.12
Total Carbon	%	0.03	0.09	0.06	0.03
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.03	0.09	0.06	0.03
Total Sulphur	%	12.03	13.20	12.62	0.59
Total Calcium	%	28.16	28.42	28.29	0.13
Total Flow	kg/h			0.31	
J - Valve					
Ash	%	98.52	99.19	98.86	0.34
Total Carbon	%	0.12	0.06	0.09	0.03
Organic Carbon	%	0.10	0.05	0.08	0.03
Inorganic Carbon	%	0.02	0.01	0.01	0.00
Total Sulphur	%	12.20	12.47	12.34	0.14
Total Calcium	%	28.06	27.50	27.78	0.28
Total Flow	kg/h			0.06	
Baghouse + Cyclone Discharge					
Ash	%	86.79	83.66	85.23	1.57
Total Carbon	%	11.10	14.57	12.84	1.74
Organic Carbon	%	10.42	13.27	11.85	1.43
Inorganic Carbon	%	0.68	1.30	0.99	0.31
Total Sulphur	%	9.19	7.94	8.57	0.62
Total Calcium	%	24.44	23.13	23.79	0.66
Total Flow	kg/h			2.29	
Standpipe					
Ash	%	89.80	96.14	92.97	3.17
Total Carbon	%	8.24	3.53	5.89	2.36
Organic Carbon	%	7.20	3.32	5.26	1.94
Inorganic Carbon	%	1.04	0.21	0.63	0.42
Total Sulphur	%	8.98	13.02	11.00	2.02
Total Calcium	%	24.42	29.97	27.20	2.77
Total Flow	kg/h			0.11	
No Weepage And Secondary Cyclone					

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO: 3
DATE: MAR. 7 /90

TIME:		5.30	6.30	7.30	8.30	9.30	10.30	11.30	12.30	13.30
Bagsample	kg		1.50				1.10			
Solids Feedrate	kg/hr	12.20	10.00	11.00	11.40	9.80	10.80	11.80	9.20	11.80
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr		18.00				13.20			
J-Valve Sample	kg		0.30							
Baghouse Discharge	kg/hr	2.20	1.40	1.60	3.70	1.70	1.75	1.70	0.30	3.30
Standpipe Discharge	kg/hr	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.10	0.10
Primary Air Differential	in. H20	30.00	30.00	30.00	30.00	29.00	30.00	30.00	30.00	32.00
Primary Air Pressure	psig	2.80	3.40	3.10	3.40	3.20	3.00	3.40	3.20	3.00
Primary Air Feedrate	kg/hr	59.07	60.07	59.57	60.07	58.74	59.41	60.07	59.74	61.35
Total Flow Differential	in. H20	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	99.80	99.80	99.80	99.80	99.80	99.80	99.80	99.80	99.80
Rotameter 1 % Flow	%	32.00	32.00	30.00	32.00	33.00	30.00	29.00	33.00	32.00
Rotameter 1 Pressure	psig		2.00	2.60	4.00	3.50	1.50	1.80	2.00	1.30
Rotameter 1 Flow	kg/hr	4.28	4.56	4.35	4.83	4.91	4.21	4.11	4.71	4.47
Rotameter 2 % Flow	%	70.00	65.00	65.00	60.00	65.00	70.00	67.00	65.00	80.00
Rotameter 2 Pressure	psig		4.00	4.00	4.20	5.50	3.20	2.60	3.00	2.00
Rotameter 2 Flow	kg/hr	9.36	9.81	9.81	9.10	10.19	10.33	9.72	9.98	11.41
Rotameter 3 % Flow	%	35.00	40.00	38.00	40.00	40.00	40.00	40.00	45.00	35.00
Rotameter 3 Pressure	psig	3.00	2.20	3.00	3.50	3.30	2.70	2.00	3.00	3.00
Rotameter 3 Flow	kg/hr	5.14	5.74	5.58	5.95	5.92	5.82	5.70	6.61	5.14
Rotameter 4 % Flow	%	80.00	78.00	80.00	80.00	80.00	81.00	85.00	80.00	85.00
Rotameter 4 Pressure	psig	3.00	3.40	3.30	3.30	4.20	3.10	3.50	3.10	3.30
Rotameter 4 Flow	kg/hr	11.74	11.58	11.84	11.84	12.13	11.92	12.65	11.78	12.58
Sum Rotameters 1 to 5	kg/hr	30.53	31.68	31.58	31.72	33.16	32.29	32.19	33.07	33.59
Rotameters Total Flow Diff.	in.H20	14.50	14.00	14.50	14.50	14.00	14.00	14.00	14.00	15.00
Rotameters Total Flow P	psig	13.00	11.70	12.80	12.80	13.00	12.80	12.50	12.60	12.60
Rotameters Total Flow	kg/hr	32.35	31.03	32.23	32.23	31.78	31.67	31.50	31.55	32.66
Sum Total Flow	kg/hr	91.42	91.10	91.80	92.30	90.52	91.07	91.57	91.29	94.02
Combustor Bottom Temp.	C	869.00	869.00	847.00	853.00	849.00	845.00	909.00	853.00	908.00
Combustor Middle Temp.	C	870.00	871.00	849.00	858.00	854.00	848.00	894.00	853.00	804.00
Combustor Top Temp.	C	883.00	883.00	859.00	861.00	862.00	854.00	922.00	867.00	919.00
Standpipe Top Temp.	C	814.00	814.00	800.00	804.00	797.00	788.00	813.00	806.00	819.00
Standpipe Middle Temp.	C	692.00	690.00	663.00	652.00	656.00	651.00	682.00	668.00	691.00
Standpipe Bottom Temp.	C	684.00	682.00	653.00	645.00	646.00	638.00	666.00	658.00	682.00
CO2 Concentration	%	14.90	14.90	13.10	15.30	15.30	15.20	16.40	14.90	14.60
O2 Concentration	%	3.10	3.10	4.30	3.70	3.80	3.90	2.60	4.30	1.10
CO Concentration	ppm	302.00	370.00	253.00	407.00	393.00	400.00	793.00	570.00	1117.00
SO2 Concentration	ppm	950.00	650.00	700.00	680.00	375.00	300.00	1000.00	400.00	1250.00
NOx Concentration	ppm	260.00	280.00	260.00	240.00	260.00	280.00	260.00	260.00	220.00

TEST NO: 3

DATE: MAR. 7 /90

TIME:		14.30	15.30	16.30	17.30	18.30	19.30	20.30	21.30
Bagsample	kg	1.50				1.25			
Solids Feedrate	kg/hr	11.80	9.00	9.40	10.80	12.40	10.20	13.60	11.60
Secondary Cyclone Sample	kg								
Secondary Cyclone Discharge	kg/hr	18.00				15.00			
J-Valve Sample	kg	0.25				0.40			
Baghouse Discharge	kg/hr	1.80	0.75	1.45	1.70	4.00	2.40	1.30	2.60
Standpipe Discharge	kg/hr	0.25	0.05	0.10	0.10	0.40	0.05	0.00	
Primary Air Differential	in. H20	33.00	33.00	39.00	35.00	30.00	30.00	32.00	32.00
Primary Air Pressure	psig	3.20	3.00	3.10	3.20	3.40	3.30	3.20	3.20
Primary Air Feedrate	kg/hr	62.66	62.31	67.92	64.53	60.07	59.91	61.70	61.70
Total Flow Differential	in. H20	22.00	22.00	22.00	22.00	23.00	24.00	23.00	23.50
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	99.80	99.80	99.80	99.80	102.04	104.23	102.04	103.14
Rotameter 1 % Flow	%	36.00	38.00	38.00	40.00	45.00	45.00	45.00	40.00
Rotameter 1 Pressure	psig	1.50	1.80	2.20	2.00	2.50	2.50		2.20
Rotameter 1 Flow	kg/hr	5.06	5.39	5.45	5.70	6.51	6.51	6.02	5.74
Rotameter 2 % Flow	%	47.00	41.00	35.00	35.00	65.00	70.00	70.00	80.00
Rotameter 2 Pressure	psig	4.20	1.80	3.00	2.80	4.00	3.00		4.20
Rotameter 2 Flow	kg/hr	7.13	5.81	5.14	5.11	9.81	10.28	9.36	12.13
Rotameter 3 % Flow	%	39.00	45.00	40.00	41.00	60.00	55.00	55.00	30.00
Rotameter 3 Pressure	psig	3.20	2.50	2.20	2.00	4.00	3.50		2.00
Rotameter 3 Flow	kg/hr	5.76	6.51	5.74	5.85	9.05	8.19	7.36	4.28
Rotameter 4 % Flow	%	80.00	82.00	81.00	80.00	80.00	70.00	71.00	75.00
Rotameter 4 Pressure	psig	3.50	3.20	3.50	3.50	3.50	3.30	3.20	3.20
Rotameter 4 Flow	kg/hr	11.91	12.10	12.06	11.91	11.91	10.36	10.48	11.07
Sum Rotameters 1 to 5	kg/hr	29.85	29.81	28.38	28.57	37.28	35.33	33.22	33.22
Rotameters Total Flow Diff.	in.H20	13.50	12.00	12.00	12.00	17.00	17.00	15.00	15.00
Rotameters Total Flow P	psig	12.60	12.80	12.80	12.80	13.00	12.80	13.00	13.00
Rotameters Total Flow	kg/hr	30.99	29.32	29.32	29.32	35.02	34.90	32.90	32.90
Sum Total Flow	kg/hr	93.64	91.63	97.24	93.85	95.10	94.80	94.60	94.60
Combustor Bottom Temp.	C	883.00	882.00	850.00	884.00	890.00	850.00	903.00	876.00
Combustor Middle Temp.	C	884.00	885.00	853.00	879.00	889.00	853.00	898.00	876.00
Combustor Top Temp.	C	899.00	897.00	864.00	898.00	902.00	864.00	913.00	888.00
Standpipe Top Temp.	C	837.00	832.00	815.00	825.00	803.00	803.00	819.00	806.00
Standpipe Middle Temp.	C	676.00	681.00	659.00	665.00	649.00	602.00	613.00	650.00
Standpipe Bottom Temp.	C	668.00	673.00	656.00	664.00	639.00	590.00	602.00	638.00
CO2 Concentration	%	13.10	14.40	9.00		16.20	14.30	17.00	15.00
O2 Concentration	%	5.50	4.10			2.20	4.70		3.80
CO Concentration	ppm	143.00	326.00	385.00	490.00	936.00	1040.00		148.00
SO2 Concentration	ppm	340.00	425.00	450.00			1600.00		2000.00
NOx Concentration	ppm	320.00	280.00	160.00		180.00	180.00	160.00	240.00

SULPHUR CAPTURE STUDY

TEST NO: 4
START : 4:30-17/06/90
FINISH: 23:30-17/06/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 1.43:1
SECONDARY CYCLONE: OFF

TEST NO: 4

FINAL RESULTS FOR MASS BALANCES:

		Avg	Std	Count	Min	Max
Bedsample	kg	1.29	0.34	4.00	0.70	1.55
Solids Feedrate	kg/hr	17.42	2.47	20.00	11.60	23.20
Cycle Recycle Sample	kg	0.00	0.00	0.00	0.00	0.00
Secondary Cyclone Recycle	kg/hr	0.00	0.00	0.00	0.00	0.00
J-Valve Sample	kg	0.46	0.52	5.00	0.15	1.50
Baghouse Discharge	kg/hr	3.57	1.05	20.00	1.70	6.10
Standpipe Discharge	kg/hr	6.83	2.76	20.00	1.90	13.50
Total Flow Differential	in. H2O	23.73	0.49	20.00	23.00	24.50
Total Flow Pressure	psig	15.00	0.00	20.00	15.00	15.00
Total Flow Feedrate	kg/hr	101.93	1.05	20.00	100.36	103.58
Weepage	kg	0.66	1.06	4.00	0.05	2.50
Combustor Top Temp.	C	867.35	13.67	20.00	848.00	903.00
CO2 Concentration	%	13.86	0.49	20.00	13.00	14.60
O2 Concentration	%	3.00	0.96	20.00	1.70	4.80
CO Concentration	ppm	291.75	94.32	20.00	162.00	467.00
SO2 Concentration	ppm	1231.25	278.26	20.00	750.00	2000.00
NOx Concentration	ppm	212.75	24.72	20.00	180.00	270.00

TEST NO: 4

OVERALL MASS BALANCE

Air Feedrate	kg/h	101.57
Nitrogen Feed Rate	kg/h	78.25
Mass flowrate of dry flue gas	kg/h	101.07
Mass flowrate of wet flue gas	kg/h	104.94
Total Input Streams	kg/h	118.99
Total Output Streams	kg/h	115.84
Overall Mass Balance Error	%	2.65
Theoretical Air Required	kg/h	86.48
Excess Air	%	17.44

CARBON BALANCE

Organic Carbon Input	kg/h	6.21
Inorganic Carbon Input	kg/h	0.09
Organic Carbon Out in Solids	kg/h	0.43
Inorganic Carbon Out in Solids	kg/h	0.04
Carbon Out in Flue Gas	kg/h	5.54
Carbon Balance Error	%	4.62
Carbon Utilization (Solid Basis)	%	93.11
Carbon Utilization (Gas Basis)	%	88.42

SULPHUR BALANCE

Sulphur Input	kg/h	1.36
Sulphur Out in Solids	kg/h	1.46
Sulphur Out in Flue Gas	kg/h	0.13
Sulphur Balance Error	%	-18.70
Sulphur Capture	%	83.30

CALCIUM BALANCE

Calcium Input	kg/h	2.43
Calcium Out in Solids	kg/h	2.57
Ca/S Ratio*		1.43
Calcium Balance Error	%	-5.78

ASH BALANCE

Ash Input	kg/h	8.97
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	3.07
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	3.71
Total Ash Input (Gas Basis)	kg/h	12.04
Total Ash Input (Solids Basis)	kg/h	12.68
Total Ash Out	kg/h	10.15
Ash Balance Error (Gas Basis)	%	15.73
Ash Balance Error (Solids Basis)	%	19.95

* Ca/S Ratio is calculated on total Sulphur and total Calcium in the input streams. The ratio, based on the free Calcium in the H.B.M. and the Sulphur in the Coal is 2:1

TEST NO: 4

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 1.43

S : 1.00

INPUT STREAMS

SPECIES		R.B.M	INPUT (kg/h)	COAL	INPUT (kg/h)
H20	%	2.99	0.26	7.29	0.63
Ash	%	13.78	1.20	89.20	7.77
Total Carbon	%	71.00	6.18	1.36	0.12
Organic Carbon	%	71.00	6.18	0.35	0.03
Inorganic Carbon	%	0.00	0.00	1.01	0.09
Sulphur	%	6.60	0.57	9.01	0.78
Calcium	%	0.00	0.00	27.88	2.43
Hydrogen	%	4.60	0.40	0.00	0.00
Nitrogen	%	1.22	0.11	0.00	0.00
Oxygen	%	2.80	0.24	2.63	0.23
Total Flow	kg/h	8.71		8.71	

FLUE GAS ANALYSIS

CO2	%	13.86
O2	%	3.00
CO	ppm	291.75
SO2	ppm	1231.25
NOx	ppm	212.75
N2	%	82.97
MOLE wt. of flue gas		30.39

TEST NO: 4

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		11:30-17/3 5	19:30-17/3 7	AVG.	STD
Weepage					
Ash	%	97.75	97.66	97.71	0.05
Total Carbon	%	0.20	0.37	0.29	0.09
Organic Carbon	%	0.00	0.20	0.10	0.10
Inorganic Carbon	%	0.20	0.17	0.19	0.02
Total Sulphur	%	15.27	15.11	15.19	0.08
Total Calcium	%	16.19	39.96	28.08	11.89
Total Flow	kg/h			0.13	
J - Valve					
Ash	%	98.69	98.69	98.69	0.00
Total Carbon	%	0.20	0.47	0.34	0.14
Organic Carbon	%	0.20	0.24	0.22	0.02
Inorganic Carbon	%	0.00	0.23	0.12	0.12
Total Sulphur	%	13.64	16.09	14.87	1.22
Total Calcium	%	26.07	28.28	27.18	1.11
Total Flow	kg/h			0.12	
Baghouse					
Ash	%	84.84	82.89	83.87	0.98
Total Carbon	%	10.48	12.70	11.59	1.11
Organic Carbon	%	10.44	12.07	11.26	0.82
Inorganic Carbon	%	0.04	0.63	0.34	0.29
Total Sulphur	%	11.35	11.88	11.62	0.27
Total Calcium	%	20.20	21.71	20.96	0.76
Total Flow	kg/h			3.57	
Standpipe					
Ash	%	97.78	97.19	97.49	0.30
Total Carbon	%	0.70	0.90	0.80	0.10
Organic Carbon	%	0.20	0.72	0.46	0.26
Inorganic Carbon	%	0.50	0.18	0.34	0.16
Total Sulphur	%	14.61	14.63	14.62	0.01
Total Calcium	%	24.33	25.23	24.78	0.45
Total Flow	kg/h			6.83	
No Secondary Cyclone					
Bedsample					
Ash	%	98.84	98.94	98.89	0.05
Total Carbon	%	0.20	0.56	0.38	0.18
Organic Carbon	%	0.20	0.20	0.20	0.00
Inorganic Carbon	%	0.00	0.36	0.18	0.18
Total Sulphur	%	13.05	12.40	12.73	0.33
Total Calcium	%	25.92	21.00	23.46	2.46
Total Flow	kg/h			0.26	

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO: 4

DATE: JUN. 17 /90

TIME:		4.3	5.3	6.3	7.3	8.3	9.3	10.3	11.3	12.3
Bedsample	kg								1.55	
Solids Feedrate	kg/hr	14.40	15.20	17.00	18.00	18.40	17.80	16.60	23.20	11.60
Secondary Cyclone Sample	kg									
Secondary Cyclone Recycle	kg/hr									
J-Valve Sample	kg				1.50				0.25	
Baghouse Discharge	kg/hr	2.10	2.80	1.70	3.10	6.10	4.10	3.60	4.20	3.60
Standpipe Discharge	kg/hr	1.90	8.10	7.60	8.10	6.40	6.20	7.60	10.10	4.10
Total Flow Differential	in. H20	23.00	23.00	24.00	24.00	24.50	24.00	24.00	24.00	24.00
Total Flow Pressure	psig	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total Flow Feedrate	kg/hr	100.36	100.36	102.52	102.52	103.58	102.52	102.52	102.52	102.52
Weepage	kg				2.50				0.05	
Combustor Top Temp.	C	855.00	854.00	869.00	903.00	889.00	888.00	867.00	853.00	859.00
CO2 Concentration	%	13.40	13.80	13.40	14.60	14.60	14.20	13.50	13.10	14.20
O2 Concentration	%	4.80	4.70	4.10	2.10	2.00	2.50	3.70	4.40	2.70
CO Concentration	ppm	243.00	198.00	320.00	406.00	279.00	316.00	232.00	211.00	467.00
SO2 Concentration	ppm	1250.00	1500.00	1300.00	1300.00	1400.00	1450.00	1100.00	775.00	750.00
NOx Concentration	ppm	250.00	230.00	220.00	185.00	185.00	190.00	230.00	240.00	180.00

TEST NO: 4
DATE: JUN. 17 /90

TIME:		13.3	14.3	15.3	16.3	17.3	18.3	19.3	20.3	21.3
Bedsample	kg			1.40				1.50		
Solids Feedrate	kg/hr	21.60	18.60	18.00	15.80	16.00	15.00	18.80	17.40	20.00
Secondary Cyclone Sample	kg									
Secondary Cyclone Recycle	kg/hr									
J-Valve Sample	kg			0.15				0.20		
Baghouse Discharge	kg/hr	5.20	4.70	3.50	4.10	4.40	3.10	1.80	3.30	3.60
Standpipe Discharge	kg/hr	13.50	9.00	7.00	3.70	5.85	3.20	8.30	5.90	10.50
Total Flow Differential	in. H2O	24.00	24.00	24.00	24.50	24.00	23.50	23.00	23.50	23.50
Total Flow Pressure	psig	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total Flow Feedrate	kg/hr	102.52	102.52	102.52	103.58	102.52	101.45	100.36	101.45	101.45
Weepage	kg			0.05				0.05		
Combustor Top Temp.	C	861.00	848.00	857.00	875.00	865.00	861.00	866.00	858.00	863.00
CO2 Concentration	%	14.50	13.60	14.00	13.80	13.30	14.10	14.40	14.00	14.20
O2 Concentration	%	1.90	3.80	2.70	3.30	3.60	2.20	1.70	2.10	2.00
CO Concentration	ppm	371.00	237.00	275.00	198.00	209.00	452.00	460.00	291.00	333.00
SO2 Concentration	ppm	1150.00	1100.00	1150.00	950.00	1650.00	2000.00	1250.00	1250.00	1100.00
NOx Concentration	ppm	180.00	215.00	220.00	270.00	240.00	200.00	185.00	200.00	205.00

TEST NO:		4	
DATE:		JUN. 17 /90	
TIME:		22.3	23.3
Bedsample	kg		0.70
Solids Feedrate	kg/hr	18.00	17.00
Secondary Cyclone Sample	kg		
Secondary Cyclone Recycle	kg/hr		
J-Valve Sample	kg		0.20
Baghouse Discharge	kg/hr	3.20	3.20
Standpipe Discharge	kg/hr	6.50	3.00
Total Flow Differential	in. H2O	23.00	23.00
Total Flow Pressure	psig	15.00	15.00
Total Flow Feedrate	kg/hr	100.36	100.36
Weepage	kg		
Combustor Top Temp.	C	878.00	878.00
CO2 Concentration	%	13.40	13.00
O2 Concentration	%	2.70	3.00
CO Concentration	ppm	162.00	175.00
SO2 Concentration	ppm	1150.00	1050.00
NOx Concentration	ppm	215.00	215.00

SULPHUR CAPTURE STUDY

TEST NO: 5
START : 00:30-18/06/90
FINISH: 21:30-18/06/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 1.6:1
SECONDARY CYCLONE: OFF

TEST NO: 5

FINAL RESULTS FOR MASS BALANCES:

		Avg	Std	Count	Min	Max
Bedsample	kg	0.95	0.50	4.00	0.45	1.50
Solids Feedrate	kg/hr	14.28	1.48	22.00	10.60	17.60
Cyclone Recycle Discharge	kg	0.00	0.00	0.00	0.00	0.00
Secondary Cyclone Recycle	kg/hr	0.00	0.00	0.00	0.00	0.00
J-Valve Sample	kg	0.28	0.08	4.00	0.20	0.40
Baghouse Discharge	kg/hr	3.60	1.37	21.00	1.70	8.70
Standpipe Discharge	kg/hr	2.94	1.56	21.00	0.45	6.20
Total Flow Differential	in. H2O	23.34	0.38	22.00	22.50	24.00
Total Flow Pressure	psig	15.00	0.00	22.00	15.00	15.00
Total Flow Feedrate	kg/hr	101.10	0.83	22.00	99.27	102.52
Weepage	kg	0.00	0.00	0.00	0.00	0.00
Combustor Top Temp.	C	864.86	18.74	22.00	829.00	902.00
CO2 Concentration	%	14.04	1.34	22.00	11.10	16.10
O2 Concentration	%	4.12	1.09	22.00	2.10	6.00
CO Concentration	ppm	206.50	26.62	22.00	166.00	256.00
SO2 Concentration	ppm	650.00	509.39	19.00	150.00	1750.00
NOx Concentration	ppm	240.45	27.30	22.00	175.00	285.00

TEST NO: 5

OVERALL MASS BALANCE

Air Feedrate	kg/h	101.10
Nitrogen Feed Rate	kg/h	77.89
Mass flowrate of dry flue gas	kg/h	102.12
Mass flowrate of wet flue gas	kg/h	105.82
Total Input Streams	kg/h	115.38
Total Output Streams	kg/h	112.58
Overall Mass Balance Error	%	2.43
Theoretical Air Required	kg/h	82.93
Excess Air	%	21.91

CARBON BALANCE

Organic Carbon Input	kg/h	5.94
Inorganic Carbon Input	kg/h	0.25
Organic Carbon Out in Solids	kg/h	0.32
Inorganic Carbon Out in Solids	kg/h	0.24
Carbon Out in Flue Gas	kg/h	5.66
Carbon Balance Error	%	-0.37
Carbon Utilization (Solid Basis)	%	94.82
Carbon Utilization (Gas Basis)	%	95.00

SULPHUR BALANCE

Sulphur Input	kg/h	0.93
Sulphur Out in Solids	kg/h	0.83
Sulphur Out in Flue Gas	kg/h	0.07
Sulphur Balance Error	%	3.39
Sulphur Capture	%	87.34

CALCIUM BALANCE

Calcium Input	kg/h	1.86
Calcium Out in Solids	kg/h	1.45
Ca/S Ratio*		1.60
Calcium Balance Error	%	22.17

ASH BALANCE

Ash Input	kg/h	5.87
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	2.14
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	2.07
Total Ash Input (Gas Basis)	kg/h	8.01
Total Ash Input (Solids Basis)	kg/h	7.93
Total Ash Out	kg/h	6.10
Ash Balance Error (Gas Basis)	%	23.91
Ash Balance Error (Solids Basis)	%	23.15

* The same basis as Test # 4.

TEST NO: 5

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 1.60

S : 1.00

INPUT STREAMS

SPECIES		COAL	H.B.M.	LIMESTONE
H2O	%	2.99	7.29	0.00
Ash	%	13.78	89.20	56.56
Total Carbon	%	71.00	1.36	11.85
Organic Carbon	%	71.00	0.35	0.00
Inorganic Carbon	%	0.00	1.01	11.85
Sulphur	%	6.60	9.01	0.00
Calcium	%	0.00	27.88	39.57
Hydrogen	%	4.60	0.00	0.00
Nitrogen	%	1.22	0.00	0.00
Oxygen	%	2.80	2.63	47.38
MASS OF COAL	kg	100.00		
MASS OF H.B.M.	kg		50.00	
MASS OF LIMESTONE	kg			21.00
Total Flow	kg/h	8.35	4.18	1.75

FLUE GAS ANALYSIS

CO2	%	14.04
O2	%	4.12
CO	ppm	206.50
SO2	ppm	650.00
NOx	ppm	240.45
N2	%	81.73
MOLE wt. of flue gas		30.44

TEST NO: 5

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		10:30-18/6 2	18:30-18/6 4	AVG.	STD
Weepage					
Ash	%	0.00	0.00	0.00	0.00
Total Carbon	%	0.00	0.00	0.00	0.00
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.00	0.00	0.00	0.00
Total Sulphur	%	0.00	0.00	0.00	0.00
Total Calcium	%	0.00	0.00	0.00	0.00
Total Flow	kg/h			0.00	
J - Valve					
Ash	%	98.39	98.47	98.43	0.04
Total Carbon	%	1.16	0.20	0.68	0.48
Organic Carbon	%	0.49	0.00	0.25	0.25
Inorganic Carbon	%	0.67	0.20	0.43	0.23
Total Sulphur	%	16.17	16.33	16.25	0.08
Total Calcium	%	26.12	24.05	25.09	1.04
Total Flow	kg/h			0.05	
Baghouse					
Ash	%	82.25	85.40	83.83	1.58
Total Carbon	%	13.06	9.95	11.51	1.56
Organic Carbon	%	7.50	8.62	8.06	0.56
Inorganic Carbon	%	11.93	1.33	6.63	5.30
Total Sulphur	%	8.79	10.66	9.73	0.94
Total Calcium	%	16.45	24.24	20.35	3.90
Total Flow	kg/h			3.60	
Standpipe					
Ash	%	97.21	97.83	97.52	0.31
Total Carbon	%	1.20	0.89	1.05	0.15
Organic Carbon	%	1.18	0.89	1.04	0.14
Inorganic Carbon	%	0.02	0.00	0.01	0.01
Total Sulphur	%	15.01	15.26	15.14	0.13
Total Calcium	%	21.65	23.74	22.70	1.05
Total Flow	kg/h			2.94	
Bedsample					
Ash	%	98.98	98.88	98.93	0.05
Total Carbon	%	0.20	0.20	0.20	0.00
Organic Carbon	%	0.20	0.20	0.20	0.00
Inorganic Carbon	%	0.00	0.00	0.00	0.00
Total Sulphur	%	13.51	14.49	14.00	0.49
Total Calcium	%	19.59	22.09	20.84	1.25
Total Flow	kg/h			0.17	

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO:		5								
DATE:		JUN. 18 /90								
TIME:			0.30	1.30	2.30	3.30	4.30	5.30	6.30	7.30	8.30
Bedsample		kg							1.50		
Solids Feedrate		kg/hr	17.60	13.00	14.00	14.00	13.20	13.40	11.80	10.60	13.80
Secondary Cyclone Sample		kg									
Secondary Cyclone Recycle		kg/hr									
J-Valve Sample		kg							0.20		
Baghouse Discharge		kg/hr	3.70	5.10	2.60	2.30	2.90	3.20	2.90	2.50	8.70
Standpipe Discharge		kg/hr	3.40	5.60	2.20	1.90	2.80	2.20	2.10	0.60	
Total Flow Differential		in. H20	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	24.00
Total Flow Pressure		psig	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total Flow Feedrate		kg/hr	100.36	100.36	100.36	100.36	100.36	100.36	100.36	100.36	102.52
Weepage		kg									
Combustor Top Temp.		C	858.00	838.00	880.00	869.00	879.00	902.00	890.00	890.00	869.00
CO2 Concentration		%	12.00	12.00	12.20	12.80	14.90	15.40	14.90	14.60	13.90
O2 Concentration		%	4.00	4.50	4.40	4.20	4.90	3.80	4.60	5.50	6.00
CO Concentration		ppm	182.00	169.00	166.00	187.00	173.00	169.00	178.00	191.00	225.00
SO2 Concentration		ppm		550.00	600.00	600.00	800.00	650.00	1000.00		1700.00
NOx Concentration		ppm	225.00	235.00	220.00	235.00	285.00	260.00	285.00	200.00	255.00

TEST NO:		5								
DATE:		JUN. 18 /90								
TIME:		9.30	10.30	11.30	12.30	13.30	14.30	15.30	16.30	17.30
Bedsample	kg		1.40				0.45			
Solids Feedrate	kg/hr	13.80	14.20	14.80	14.00	15.40	16.40	15.80	14.60	16.00
Secondary Cyclone Sample	kg									
Secondary Cyclone Recycle	kg/hr									
J-Valve Sample	kg		0.40				0.25			
Baghouse Discharge	kg/hr	3.40	3.70	3.30	3.40		4.90	3.40	4.10	3.80
Standpipe Discharge	kg/hr	1.20	0.80	0.45	1.70	4.20	6.20	3.20	4.70	3.50
Total Flow Differential	in. H20	23.50	24.00	22.50	23.50	23.50	23.50	23.50	23.50	23.50
Total Flow Pressure	psig	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total Flow Feedrate	kg/hr	101.45	102.52	99.27	101.45	101.45	101.45	101.45	101.45	101.45
Weepage	kg									
Combustor Top Temp.	C	876.00	870.00	879.00	871.00	863.00	844.00	846.00	844.00	836.00
CO2 Concentration	%	15.90	15.60	16.10	15.60	14.00	14.10	14.60	13.20	14.40
O2 Concentration	%	3.10	3.80	3.00	2.90	4.60	4.70	4.00	5.80	4.50
CO Concentration	ppm	256.00	237.00	230.00	225.00	219.00	224.00	239.00	213.00	235.00
SO2 Concentration	ppm	1750.00	1650.00	750.00		350.00	350.00	300.00	300.00	250.00
NOx Concentration	ppm	220.00	210.00	220.00	175.00	265.00	245.00	240.00	225.00	240.00

TEST NO:		5			
DATE:		JUN. 18 /90			
TIME:		18.30	19.30	20.30	21.30
Bedsample	kg	0.45			
Solids Feedrate	kg/hr	14.40	15.40	13.80	14.20
Secondary Cyclone Sample	kg				
Secondary Cyclone Recycle	kg/hr				
J-Valve Sample	kg	0.25			
Baghouse Discharge	kg/hr	3.50	1.70	3.40	3.00
Standpipe Discharge	kg/hr	3.60	3.10	4.90	3.30
Total Flow Differential	in. H20	23.50	23.50	23.50	24.00
Total Flow Pressure	psig	15.00	15.00	15.00	15.00
Total Flow Feedrate	kg/hr	101.45	101.45	101.45	102.52
Wrapage	kg				
Combustor Top Temp.	C	829.00	857.00	865.00	872.00
CO2 Concentration	%	13.70	14.20	11.10	13.60
O2 Concentration	%	5.50	2.30	2.10	2.50
CO Concentration	ppm	230.00	210.00	188.00	197.00
SO2 Concentration	ppm	250.00	150.00	150.00	200.00
NOx Concentration	ppm	245.00	265.00	260.00	280.00

SULPHUR CAPTURE STUDY

TEST NO: 6
START : 15:30-20/03/90
FINISH: 06:30-21/03/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 2.0:1
SECONDARY CYCLONE: OFF

TEST NO: 6

FINAL RESULTS FOR MASS BALANCES:		Avg	Std	Count	Min	Max
Bedsample	kg	1.50	0.14	3.00	1.30	1.70
Solids Feedrate	kg/hr	13.24	1.36	16.00	9.80	15.20
Cycle Recycle Sample	kg	0.00	0.00	0.00	0.00	0.00
Secondary Cyclone Recycle	kg/hr	18.00	1.96	3.00	15.60	20.40
J-Valve Sample	kg	0.27	0.10	3.00	0.15	0.40
Baghouse Discharge	kg/hr	4.94	1.93	16.00	0.50	9.70
Standpipe Discharge	kg/hr	0.24	0.42	15.00	0.01	1.80
Total Flow Differential	in. H2O	19.06	1.95	16.00	18.00	23.00
Total Flow Pressure	psig	16.00	0.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	92.62	4.71	15.00	90.27	102.04
Weepage	kg	0.00	0.00	0.00	0.00	0.00
Combustor Top Temp.	C	859.63	21.45	16.00	808.00	893.00
CO2 Concentration	%	14.30	2.19	15.00	7.40	16.60
O2 Concentration	%	4.18	2.34	15.00	1.80	11.70
CO Concentration	ppm	250.27	94.04	15.00	115.00	515.00
SO2 Concentration	ppm	1235.71	296.67	14.00	550.00	1500.00
NOx Concentration	ppm	48.13	69.82	15.00	2.00	180.00

TEST NO: 6

OVERALL MASS BALANCE

Air Feedrate	kg/h	102.62
Nitrogen Feed Rate	kg/h	79.07
Mass flowrate of dry flue gas	kg/h	105.57
Mass flowrate of wet flue gas	kg/h	109.72
Total Input Streams	kg/h	115.86
Total Output Streams	kg/h	115.51
Overall Mass Balance Error	%	0.30
Theoretical Air Required	kg/h	92.75
Excess Air	%	10.64

CARBON BALANCE

Organic Carbon Input	kg/h	6.63
Inorganic Carbon Input	kg/h	0.46
Organic Carbon Out in Solids	kg/h	0.78
Inorganic Carbon Out in Solids	kg/h	0.09
Carbon Out in Flue Gas	kg/h	5.95
Carbon Balance Error	%	3.83
Carbon Utilization (Solid Basis)	%	88.95
Carbon Utilization (Gas Basis)	%	84.93

SULPHUR BALANCE

Sulphur Input	kg/h	0.62
Sulphur Out in Solids	kg/h	0.49
Sulphur Out in Flue Gas	kg/h	0.14
Sulphur Balance Error	%	-2.33
Sulphur Capture	%	77.81

CALCIUM BALANCE

Calcium Input	kg/h	1.54
Calcium Out in Solids	kg/h	1.54
Ca/S Ratio		2.00
Calcium Balance Error	%	-0.20

ASH BALANCE

Ash Input	kg/h	3.49
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	1.20
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	1.24
Total Ash Input (Gas Basis)	kg/h	4.69
Total Ash Input (Solids Basis)	kg/h	4.73
Total Ash Out	kg/h	4.80
Ash Balance Error (Gas Basis)	%	-2.25
Ash Balance Error (Solids Basis)	%	-1.47

TEST NO: 6

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 2.00

S : 1.00

INPUT STREAMS

SPECIES		COAL	LIMESTONE
H2O	%	2.99	0.00
Ash	%	13.78	56.56
Total Carbon	%	71.00	11.85
Organic Carbon	%	71.00	0.00
Inorganic Carbon	%	0.00	11.85
Sulphur	%	6.60	0.00
Calcium	%	0.00	39.57
Hydrogen	%	4.60	0.00
Nitrogen	%	1.22	0.00
Oxygen	%	2.80	47.38
MASS OF COAL	kg	100.00	
MASS OF LIMESTONE	kg		41.71
Total Flow	kg/h	9.34	3.90

FLUE GAS ANALYSIS

CO2	%	14.30
O2	%	4.18
CO	ppm	250.27
SO2	ppm	1235.71
NOx	ppm	48.13
N2	%	81.37
MOLE wt. of flue gas		30.51

TEST NO: 6

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		19:30-20/3 3	23:30-20/3 4	AVG.	STD
Bedsample					
Ash	%	98.73	99.41	99.07	0.34
Total Carbon	%	1.22	0.46	0.84	0.38
Organic Carbon	%	0.12	0.00	0.06	0.06
Inorganic Carbon	%	1.10	0.46	0.78	0.32
Total Sulphur	%	13.06	13.17	13.12	0.05
Total Calcium	%	31.85	31.21	31.53	0.32
CaCO3	%	9.34	3.83	6.59	2.76
CaO	%	11.72	15.33	13.53	1.80
Ca(OH)2	%	1.48	0.74	1.11	0.37
CaSO4	%	53.02	62.31	57.67	4.65
Total Flow	kg/h			0.28	
J - Valve					
Ash	%	99.05	98.60	98.83	0.23
Total Carbon	%	0.71	0.92	0.82	0.11
Organic Carbon	%	0.00	0.35	0.18	0.18
Inorganic Carbon	%	0.71	0.57	0.64	0.07
Total Sulphur	%	13.50	14.11	13.81	0.30
Total Calcium	%	33.27	32.81	33.04	0.23
CaCO3	%	5.91	4.75	5.33	0.58
CaO	%	17.22	16.20	16.71	0.51
Ca(OH)2	%	1.11	1.85	1.48	0.37
CaSO4	%	59.47	62.36	60.92	1.45
Total Flow	kg/h			0.05	
Baghouse + Secondary Cyclone Recycle					
Ash	%	82.36	80.67	81.52	0.84
Total Carbon	%	15.40	17.27	16.34	0.93
Organic Carbon	%	13.55	15.88	14.72	1.17
Inorganic Carbon	%	1.85	1.39	1.62	0.23
Total Sulphur	%	7.84	8.30	8.07	0.23
Total Calcium	%	26.58	25.69	26.14	0.44
CaCO3	%	15.42	11.58	13.50	1.92
CaO	%	11.32	10.17	10.75	0.58
Ca(OH)2	%	8.51	10.36	9.44	0.92
CaSO4	%	26.29	27.88	27.09	0.80
Total Flow	kg/h			5.23	
Standpipe					
Ash	%	92.58	83.62	88.10	4.48
Total Carbon	%	5.64	9.39	7.52	1.88
Organic Carbon	%	3.24	9.05	6.15	2.91
Inorganic Carbon	%	2.40	0.34	1.37	1.03
Total Sulphur	%	12.48	11.72	12.10	0.38
Total Calcium	%	32.66	29.77	31.21	1.44
CaCO3	%	11.67	2.83	7.25	4.42
CaO	%	16.23	10.66	13.45	2.79
Ca(OH)2	%	3.70	5.55	4.63	0.92
CaSO4	%	51.69	39.92	45.81	5.88
Total Flow	kg/h			0.24	

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO: 6
DATE: MAR. 20 /90

TIME:		15.30	16.30	17.30	18.30	19.30	20.30	21.30	22.30	23.30
Bedsample	kg	1.30				1.50				1.70
Solids Feedrate	kg/hr	13.60	12.40	9.80	12.80	14.20	15.20	14.60	13.00	14.40
Secondary Cyclone Sample	kg									
Secondary Cyclone Recycle	kg/hr	15.60				18.00				20.40
J-Valve Sample	kg	0.15				0.25				0.40
Baghouse Discharge	kg/hr	5.80	6.20	2.00	4.50	4.90	4.80	5.60	0.50	9.70
Standpipe Discharge	kg/hr	1.80	0.20	0.10	0.05	0.10	0.10	0.10		0.20
Primary Air Differential	in. H20	26.00	26.00	28.00	27.00	27.50	28.00	28.00	27.00	27.00
Primary Air Pressure	psig	2.70	2.80	2.50	2.60	2.80	3.00	2.80	2.50	2.00
Primary Air Feedrate	kg/hr	54.83	54.99	56.58	55.72	56.55	57.39	57.07	55.56	54.74
Total Flow Differential	in. H20	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	90.27	90.27	90.27	90.27	90.27	90.27	90.27	90.27	90.27
Rotameter 1 % Flow	%	44.00	44.00	41.00	42.00	40.00	40.00	42.00	40.00	40.00
Rotameter 1 Pressure	psig	1.30	1.50	1.20	1.60	1.70	1.50	1.60	1.50	1.70
Rotameter 1 Flow	kg/hr	6.14	6.18	5.70	5.92	5.65	5.62	5.92	5.62	5.65
Rotameter 2 % Flow	%	48.00	49.00	40.00	44.00	42.00	35.00	36.00	40.00	38.00
Rotameter 2 Pressure	psig	2.30	1.90	1.70	4.10	19.00	3.70	3.50	1.70	2.00
Rotameter 2 Flow	kg/hr	6.91	6.97	5.65	6.66	8.51	5.24	5.36	5.65	5.42
Rotameter 3 % Flow	%	41.00	40.00	45.00	43.00	45.00	40.00	40.00	36.00	35.00
Rotameter 3 Pressure	psig	2.80	2.00	1.80	2.90	2.00	6.00	5.00	2.00	2.00
Rotameter 3 Flow	kg/hr	5.98	5.70	6.38	6.29	6.42	6.35	6.19	5.13	4.99
Rotameter 4 % Flow	%	71.00	69.00	61.00	70.00	70.00	70.00	70.00	70.00	70.00
Rotameter 4 Pressure	psig	1.80	12.90	13.00	13.00	12.80				
Rotameter 4 Flow	kg/hr	10.06	12.65	11.20	12.85	12.81	9.36	9.36	9.36	9.36
Sum Rotameters 1 to 5	kg/hr	29.09	31.50	28.93	31.72	33.38	26.57	26.83	25.77	25.42
Rotameters Total Flow Diff.	in.H20	16.00	15.00	15.00	16.00	16.00	15.00	15.00	15.00	16.00
Rotameters Total Flow P	psig	12.60	12.60	12.60	12.60	12.40	12.50	12.40	12.40	12.60
Rotameters Total Flow	kg/hr	33.73	32.66	32.66	33.73	33.61	32.60	32.54	32.54	33.73
Sum Total Flow	kg/hr	88.57	87.65	89.24	89.45	90.16	89.99	89.61	88.10	88.47
Combustor Bottom Temp.	C	813.00	858.00	793.00	822.00	866.00	856.00	856.00	837.00	845.00
Combustor Middle Temp.	C	829.00	876.00	809.00	838.00	884.00	873.00	874.00	855.00	863.00
Combustor Top Temp.	C	826.00	872.00	808.00	836.00	881.00	871.00	871.00	853.00	860.00
Standpipe Top Temp.	C	789.00	828.00	779.00	794.00	832.00	836.00	839.00	831.00	831.00
Standpipe Middle Temp.	C	758.00	820.00	690.00	725.00	768.00	779.00	799.00	795.00	786.00
Standpipe Bottom Temp.	C	753.00	816.00	688.00	721.00	765.00	777.00	798.00	793.00	784.00
CO2 Concentration	%	15.80		13.30	14.80	16.30	16.30	7.40	14.20	15.20
O2 Concentration	%	3.20		4.70	3.90	2.20	1.80	11.70	4.40	2.60
CO Concentration	ppm	349.00		252.00	255.00	313.00	515.00	240.00	289.00	227.00
SO2 Concentration	ppm	900.00		550.00	800.00	1200.00	1400.00	1500.00	1250.00	1500.00
NOx Concentration	ppm	180.00		100.00	180.00	180.00	7.00	2.00	7.00	7.00

WATER SPRAY

LOCATION :		RECYCLE	YES	LOWER PART (NO)					
WATER FLOW	%	26.00	26.00	25.00	25.00	25.00	30.00	30.00	30.00
WATER PRESSURE	psig	61.00	62.00	61.00	59.00	60.00	61.00	61.00	61.00
AIR FLOW	%	22.00	22.00	22.00	22.00	22.00	20.00	20.00	20.00
AIR PRESSURE	psig	59.00	60.00	60.00	59.00	60.00	62.00	60.00	60.00

TEST NO:		6						
DATE:		MAR. 20 /90						
TIME:		0.30	1.30	2.30	3.30	4.30	5.30	6.30
Bedsample	kg							
Solids Feedrate	kg/hr	13.00	13.40	12.40	14.40	14.40	13.20	11.00
Secondary Cyclone Sample	kg							
Secondary Cyclone Recycle	kg/hr							
J-Valve Sample	kg							
Baghouse Discharge	kg/hr	5.30	6.80	5.10	4.60	5.40	4.00	3.90
Standpipe Discharge	kg/hr	0.10	0.10	0.10	0.10	0.30	0.10	0.10
Primary Air Differential	in. H20	28.00	28.00	30.00	30.00	30.00	30.00	28.00
Primary Air Pressure	psig	2.50	1.70	3.00	3.00	3.50	3.60	2.70
Primary Air Feedrate	kg/hr	56.58	55.24		59.41	60.24	60.40	56.90
Total Flow Differential	in. H20	18.00	18.00	20.00	23.00	23.00	23.00	18.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	90.27	90.27		102.04	102.04	102.04	90.27
Rotameter 1 % Flow	%	44.00	40.00	40.00	55.00	55.00	50.00	40.00
Rotameter 1 Pressure	psig	2.00	1.30	1.50	1.20	2.00	2.50	1.70
Rotameter 1 Flow	kg/hr	6.27	5.58	5.62	7.65	7.84	7.23	5.65
Rotameter 2 % Flow	%	40.00	40.00	40.00	45.00	50.00	50.00	39.00
Rotameter 2 Pressure	psig	2.00	1.80	2.00	1.50	2.00	2.00	1.60
Rotameter 2 Flow	kg/hr	5.70	5.67	5.70	6.32	7.13	7.13	5.49
Rotameter 3 % Flow	%	38.00	40.00	40.00	45.00	47.00	50.00	37.00
Rotameter 3 Pressure	psig	1.70	1.70	1.70	2.00	1.70	2.70	1.70
Rotameter 3 Flow	kg/hr	5.37	5.65	5.65	6.42	6.64	7.28	5.23
Rotameter 4 % Flow	%	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Rotameter 4 Pressure	psig							
Rotameter 4 Flow	kg/hr	9.36	9.36		9.36	9.36	9.36	9.36
Sum Rotameters 1 to 5	kg/hr	26.71	26.27		29.75	30.98	31.00	25.74
Rotameters Total Flow Diff.	in.H20	16.00	15.00		15.00	15.00	15.00	14.00
Rotameters Total Flow P	psig	12.80	12.60		13.00	13.00	12.80	13.00
Rotameters Total Flow	kg/hr	33.86	32.66		32.90	32.90	32.78	31.78
Sum Total Flow	kg/hr	90.43	87.90		92.31	93.14	93.18	88.69
Combustor Bottom Temp.	C	836.00	840.00	854.00	881.00	874.00	838.00	855.00
Combustor Middle Temp.	C	853.00	857.00	873.00	897.00	891.00	855.00	871.00
Combustor Top Temp.	C	852.00	855.00	870.00	893.00	886.00	853.00	867.00
Standpipe Top Temp.	C	827.00	828.00	840.00	832.00	829.00	816.00	824.00
Standpipe Middle Temp.	C	772.00	791.00	800.00	744.00	776.00	702.00	762.00
Standpipe Bottom Temp.	C	771.00	788.00	798.00	737.00	770.00	695.00	762.00
CO2 Concentration	%	14.70	15.10	11.90	14.50	16.60	14.10	14.30
O2 Concentration	%	3.70	3.50	6.60	4.40	1.90	4.10	4.00
CO Concentration	ppm	238.00	209.00	151.00	261.00	213.00	127.00	115.00
SO2 Concentration	ppm	1500.00	1350.00		1000.00	1500.00	1500.00	1350.00
NOx Concentration	ppm	7.00	7.00	6.00	10.00	10.00	10.00	9.00

WATER SPRAY

					(2nd PORT)
WATER FLOW	30.00	28.00	25.00		0.00
WATER PRESSURE	61.00	60.00	60.00		0.00
AIR FLOW	20.00	20.00	18.00		22.00
AIR PRESSURE	60.00	60.00	60.00		62.00

SULPHUR CAPTURE STUDY

TEST NO: 7
START : 07:30-21/03/90
FINISH: 22:30-22/03/90
LIMESTONE TYPE: HAVELOCK
Ca/S RATIO: 2.0:1
SECONDARY CYCLONE: OFF

TEST NO: 7

FINAL RESULTS FOR MASS BALANCES:		Avg	Std	Count	Min	Max
Bedsample	kg	1.40	0.08	3.00	1.30	1.50
Solids Feedrate	kg/hr	12.24	1.83	14.00	8.80	17.20
Cycle Recycle Sample	kg	0.00	0.00	0.00	0.00	0.00
Secondary Cyclone Discharge	kg/hr	0.00	0.00	0.00	0.00	0.00
J-Valve Sample	kg	0.17	0.02	3.00	0.15	0.20
Baghouse Discharge	kg/hr	4.81	1.22	15.00	3.50	7.80
Standpipe Discharge	kg/hr	0.21	0.34	15.00	0.05	1.20
Total Flow Differential	in. H2O	18.43	1.35	14.00	17.00	23.00
Total Flow Pressure	psig	16.00	0.00	14.00	16.00	16.00
Total Flow Feedrate	kg/hr	91.36	3.30	13.00	87.73	102.04
Weepage	kg	0.00	0.00	0.00	0.00	0.00
Combustor Top Temp.	C	877.40	16.27	15.00	844.00	898.00
CO2 Concentration	%	13.05	0.73	13.00	11.50	13.90
O2 Concentration	%	4.68	0.87	13.00	3.40	6.50
CO Concentration	ppm	129.54	41.58	13.00	90.00	239.00
SO2 Concentration	ppm	1380.77	159.97	13.00	1100.00	1600.00
NOx Concentration	ppm	185.23	69.96	13.00	8.00	260.00

TEST NO: 7

OVERALL MASS BALANCE

Air Feedrate	kg/h	101.36
Nitrogen Feed Rate	kg/h	78.09
Mass flowrate of dry flue gas	kg/h	101.89
Mass flowrate of wet flue gas	kg/h	105.72
Total Input Streams	kg/h	113.60
Total Output Streams	kg/h	111.06
Overall Mass Balance Error	%	2.24
Theoretical Air Required	kg/h	85.78
Excess Air	%	18.16

CARBON BALANCE

Organic Carbon Input	kg/h	6.13
Inorganic Carbon Input	kg/h	0.43
Organic Carbon Out in Solids	kg/h	0.52
Inorganic Carbon Out in Solids	kg/h	0.08
Carbon Out in Flue Gas	kg/h	5.26
Carbon Balance Error	%	10.69
Carbon Utilization (Solid Basis)	%	92.15
Carbon Utilization (Gas Basis)	%	81.23

SULPHUR BALANCE

Sulphur Input	kg/h	0.57
Sulphur Out in Solids	kg/h	0.50
Sulphur Out in Flue Gas	kg/h	0.15
Sulphur Balance Error	%	-13.68
Sulphur Capture	%	73.97

CALCIUM BALANCE

Calcium Input	kg/h	1.43
Calcium Out in Solids	kg/h	1.47
Ca/S Ratio		2.00
Calcium Balance Error	%	-3.21

ASH BALANCE

Ash Input	kg/h	3.23
Ash formed due to Sulphur Fixation (Gas Basis)	kg/h	1.05
Ash formed due to Sulphur Fixation (solids Basis)	kg/h	1.25
Total Ash Input (Gas Basis)	kg/h	4.28
Total Ash Input (Solids Basis)	kg/h	4.48
Total Ash Out	kg/h	4.68
Ash Balance Error (Gas Basis)	%	-9.24
Ash Balance Error (Solids Basis)	%	-4.48

TEST NO: 7

CHEMICAL COMPOSITIONS OF FEED & FLUE GAS

CALCIUM TO SULFUR RATIO

Ca : 2.00

S : 1.00

INPUT STREAMS

SPECIES		COAL	LIMESTONE
H2O	%	2.99	0.00
Ash	%	13.78	56.56
Total Carbon	%	71.00	11.85
Organic Carbon	%	71.00	0.00
Inorganic Carbon	%	0.00	11.85
Sulphur	%	6.60	0.00
Calcium	%	0.00	39.57
Hydrogen	%	4.60	0.00
Nitrogen	%	1.22	0.00
Oxygen	%	2.80	47.38
MASS OF COAL	kg	100.00	
MASS OF LIMESTONE	kg		41.71
Total Flow	kg/h	8.64	3.60

FLUE GAS ANALYSIS

CO2	%	13.05
O2	%	4.68
CO	ppm	129.54
SO2	ppm	1380.77
NOx	ppm	185.23
N2	%	82.11
MOLE wt. of flue gas		30.33

TEST NO: 7

CHEMICAL ANALYSIS AND FLOW RATES OF THE OUTPUT STREAMS

SPECIES		11:30-21/3 1	19:30-21/3 3	AVG.	STD
Bedsample					
Ash	%	99.58	99.44	99.51	0.07
Total Carbon	%	0.27	0.40	0.34	0.07
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.27	0.40	0.34	0.07
Total Sulphur	%	16.13	15.99	16.06	0.07
Total Calcium	%	34.10	33.27	33.69	0.41
CaCO3	%	2.25	3.33	2.79	0.54
CaO	%	13.86	14.36	14.11	0.25
Ca(OH)2	%	<0.05	<0.05	0.00	0.00
CaSO4	%	79.22	73.71	76.47	2.76
Total Flow	kg/h			0.28	
J - Valve					
Ash	%	99.37	99.71	99.54	0.17
Total Carbon	%	0.15	0.26	0.21	0.06
Organic Carbon	%	0.00	0.00	0.00	0.00
Inorganic Carbon	%	0.15	0.26	0.21	0.06
Total Sulphur	%	16.14	16.30	16.22	0.08
Total Calcium	%	34.10	33.88	33.99	0.11
CaCO3	%	0.32	2.17	1.25	0.93
CaO	%	15.06	14.31	14.69	0.38
Ca(OH)2	%	0.74	2.59	1.67	0.93
CaSO4	%	77.55	72.73	75.14	2.41
Total Flow	kg/h			0.03	
Baghouse					
Ash	%	86.80	86.34	86.57	0.23
Total Carbon	%	12.28	12.16	12.22	0.06
Organic Carbon	%	10.05	11.13	10.59	0.54
Inorganic Carbon	%	2.23	1.03	1.63	0.60
Total Sulphur	%	9.03	8.45	8.74	0.29
Total Calcium	%	28.07	25.78	26.93	1.14
CaCO3	%	18.58	8.58	13.58	5.00
CaO	%	12.17	10.84	11.51	0.67
Ca(OH)2	%	4.44	5.92	5.18	0.74
CaSO4	%	32.47	38.79	35.63	3.16
Total Flow	kg/h			4.81	
Standpipe					
Ash	%	95.69	94.84	95.27	0.42
Total Carbon	%	3.30	3.31	3.31	0.01
Organic Carbon	%	2.69	2.53	2.61	0.08
Inorganic Carbon	%	0.61	0.78	0.70	0.09
Total Sulphur	%	14.04	13.33	13.69	0.35
Total Calcium	%	32.95	33.56	33.26	0.30
CaCO3	%	5.08	6.50	5.79	0.71
CaO	%	15.78	15.43	15.61	0.17
Ca(OH)2	%	2.22	3.70	2.96	0.74
CaSO4	%	73.68	61.00	67.34	6.34
Total Flow	kg/h			0.21	

SULPHUR CAPTURE EXPERIMENTAL DATA

TEST NO: 7
DATE: MAR. 20 /90

TIME:		7.30	8.30	9.30	10.30	11.30	12.30	13.30	14.30	15.30
Bedsample	kg					1.30				1.40
Solids Feedrate	kg/hr	12.80	13.20	12.00	12.40	10.80	17.20	8.80	12.60	13.20
Secondary Cyclone Sample	kg									
Secondary Cyclone Discharge	kg/hr									
J-Valve Sample	kg					0.15				0.15
Baghouse Discharge	kg/hr	4.10	6.50	4.30	5.40	4.10	4.00	6.30	4.90	5.40
Standpipe Discharge	kg/hr	0.10	0.10	0.90	1.20	0.10	0.05	0.10	0.05	0.05
Primary Air Differential	in. H20	28.00	28.50	26.00	24.00	26.00	24.00	24.00	26.00	24.00
Primary Air Pressure	psig	2.50	2.90	2.60	2.90	2.70	2.60	2.50	2.40	2.60
Primary Air Feedrate	kg/hr	56.58	57.74	54.68	52.98	54.83	52.53	52.38	54.36	52.53
Total Flow Differential	in. H20	18.00	18.00	19.00	18.00	19.00	18.00	18.00	18.00	18.00
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Total Flow Feedrate	kg/hr	90.27	90.27	92.74	90.27	92.74	90.27	90.27	90.27	90.27
Rotameter 1 % Flow	%	42.00	41.00	53.00	55.00	47.00	46.00	49.00	48.00	47.00
Rotameter 1 Pressure	psig	2.00	1.70	1.40	1.90	1.70	1.70	1.40	1.50	1.60
Rotameter 1 Flow	kg/hr	5.99	5.79	7.42	7.82	6.64	6.50	6.86	6.74	6.62
Rotameter 2 % Flow	%	39.00	37.00	46.00	44.00	48.00	42.00	53.00	55.00	62.00
Rotameter 2 Pressure	psig	4.50	2.10	2.80	3.30	3.80	2.00	3.50	3.60	2.00
Rotameter 2 Flow	kg/hr	5.96	5.29	6.71	6.51	7.20	5.99	7.89	8.21	8.84
Rotameter 3 % Flow	%	35.00	36.00	51.00	46.00	50.00	48.00	45.00	48.00	47.00
Rotameter 3 Pressure	psig	3.50	2.20	3.20	3.50	3.40	2.40	3.20	3.00	2.20
Rotameter 3 Flow	kg/hr	5.21	5.16	7.53	6.85	7.42	6.93	6.64	7.05	6.74
Rotameter 4 % Flow	%		69.00	71.00	71.00	72.00	70.00	71.00	72.00	70.00
Rotameter 4 Pressure	psig		13.10	12.80	12.90	12.70	13.00	12.80	12.90	13.00
Rotameter 4 Flow	kg/hr		12.69	12.99	13.01	13.15	12.85	12.99	13.20	12.85
Sum Rotameters 1 to 5	kg/hr	17.16	28.94	34.65	34.19	34.42	32.27	34.38	35.19	35.06
Rotameters Total Flow Diff.	in.H20	16.00	15.00	15.00	16.00	16.00	15.00	15.00	15.00	16.00
Rotameters Total Flow P	psig	12.60	12.60	12.60	12.60	12.40	12.50	12.40	12.40	12.60
Rotameters Total Flow	kg/hr	33.73	32.66	32.66	33.73	33.61	32.60	32.54	32.54	33.73
Sum Total Flow	kg/hr	90.31	90.40	87.34	86.72	88.44	85.13	84.92	86.90	86.26
Combustor Bottom Temp.	C	859.00	846.00	876.00	890.00	886.00	885.00	871.00	883.00	851.00
Combustor Middle Temp.	C	875.00	863.00	892.00	900.00	901.00	902.00	886.00	901.00	866.00
Combustor Top Temp.	C	872.00	860.00	887.00	891.00	896.00	898.00	881.00	896.00	862.00
Standpipe Top Temp.	C	836.00	827.00	844.00	831.00	841.00	851.00	836.00	851.00	827.00
Standpipe Middle Temp.	C	742.00	775.00	821.00	805.00	824.00	797.00	804.00	798.00	769.00
Standpipe Bottom Temp.	C	741.00	773.00	817.00	789.00	817.00	791.00	796.00	792.00	762.00
CO2 Concentration	%	13.50	13.90	13.90	12.90	13.30	13.30	12.60	13.20	13.40
O2 Concentration	%	4.90	4.20	4.00	5.00	4.30	4.00	5.00	4.50	3.90
CO Concentration	ppm	107.00	121.00	106.00	90.00	102.00	114.00	121.00	102.00	239.00
SO2 Concentration	ppm	1250.00	1100.00	1300.00	1500.00	1200.00	1400.00	1300.00	1200.00	1450.00
NOx Concentration	ppm	8.00	140.00	120.00	100.00	240.00	220.00	240.00	220.00	220.00

WATER SPRAY

	LOCATION : RECYCLE	YES	NO						
WATER FLOW	%	25.00	25.00	27.00	26.00	27.00	26.00	27.00	25.00
WATER PRESSURE	psig	60.00	62.00	59.00	58.00	58.00	58.00	58.00	35.00
AIR FLOW	%	20.00	22.00	21.00	22.00	22.00	22.00	21.00	18.00
AIR PRESSURE	psig	60.00	64.00	61.00	60.00	60.00	60.00	59.00	35.00

TEST NO: 7

DATE: MAR. 20 /90

TIME:		16.30	17.30	18.30	19.30	20.30	21.30	22.30
Bedsample	kg				1.50			
Solids Feedrate	kg/hr	11.20	11.20	12.20	13.20	10.60		
Secondary Cyclone Sample	kg							
Secondary Cyclone Discharge	kg/hr							
J-Valve Sample	kg				0.20			
Baghouse Discharge	kg/hr	4.90	3.50	4.00	3.50	3.50		7.80
Standpipe Discharge	kg/hr	0.05	0.05	0.05	0.05	0.10		0.20
Primary Air Differential	in. H20	23.00	22.50	22.00	21.00	30.00		
Primary Air Pressure	psig	2.40	2.70	2.60	2.40	3.40		
Primary Air Feedrate	kg/hr	51.13	51.01		48.85	60.07		
Total Flow Differential	in. H20	17.00	18.00	18.00	18.00	23.00		
Total Flow Pressure	psig	16.00	16.00	16.00	16.00	16.00		
Total Flow Feedrate	kg/hr	87.73	90.27		90.27	102.04		
Rotameter 1 % Flow	%	47.00	49.00	48.00	47.00	50.00		
Rotameter 1 Pressure	psig	1.70	1.40	1.70	1.50	1.50		
Rotameter 1 Flow	kg/hr	6.64	6.86	6.78	6.60	7.02		
Rotameter 2 % Flow	%	55.00	59.00	65.00	58.00	70.00		
Rotameter 2 Pressure	psig	4.00	1.80	2.00	2.50	4.00		
Rotameter 2 Flow	kg/hr	8.30	8.36	9.27	8.39	10.56		
Rotameter 3 % Flow	%	45.00	50.00	50.00	48.00	40.00		
Rotameter 3 Pressure	psig	3.20	2.80	2.10	2.60	3.00		
Rotameter 3 Flow	kg/hr	6.64	7.30	7.15	6.97	5.87		
Rotameter 4 % Flow	%	70.00	71.00	71.00	70.00	70.00		
Rotameter 4 Pressure	psig	12.80	12.60	2.80	13.00	13.00		
Rotameter 4 Flow	kg/hr	12.81	12.94		12.85	12.85		
Sum Rotameters 1 to 5	kg/hr	34.39	35.46		34.81	36.31	0.00	0.00
Rotameters Total Flow Diff.	in.H20	16.00	15.00		15.00	15.00	15.00	14.00
Rotameters Total Flow P	psig	12.80	12.60		13.00	13.00	12.80	13.00
Rotameters Total Flow	kg/hr	33.86	32.66		32.90	32.90	32.78	31.78
Sum Total Flow	kg/hr	84.98	83.67		81.75	92.97	32.78	31.78
Combustor Bottom Temp.	C	855.00	866.00	883.00	873.00	828.00		843.00
Combustor Middle Temp.	C	868.00	882.00	896.00	888.00	847.00		858.00
Combustor Top Temp.	C	864.00	878.00	891.00	885.00	844.00		856.00
Standpipe Top Temp.	C	833.00	839.00	840.00	844.00	827.00		838.00
Standpipe Middle Temp.	C	806.00	797.00	796.00	781.00	642.00		685.00
Standpipe Bottom Temp.	C	799.00	790.00	788.00	774.00	636.00		670.00
CO2 Concentration	%	11.50	11.60	13.60	12.90			
O2 Concentration	%	6.50	6.30	3.40	4.80			
CO Concentration	ppm	140.00	197.00	147.00	98.00			
SO2 Concentration	ppm	1500.00	1550.00	1600.00	1600.00			
NOx Concentration	ppm	200.00	200.00	240.00	260.00			

WATER SPRAY

WATER FLOW	26.00	26.00	28.00	26.00	27.00
WATER PRESSURE	58.00	56.00	60.00	58.00	58.00
AIR FLOW	20.00	22.00	22.00	21.00	21.00
AIR PRESSURE	60.00	56.00	61.00	59.00	59.00

APPENDIX C

Bed Material Hot and Cold Hydration Results

REPORT NUMBER: PC/90/030 DATE: April 26, 1990

JOB NUMBER: 04090**080/1026**

TO: P. Salib
Dept. 8
(Job #8058)

Analysis of Bed Materials

Sieve Analysis (%)

		Original	"Cold Drip"	"Hot Water"
+16 mesh	1 mm	5.53	3.74	1.82
-16 +25 mesh	0.707 mm	19.97	16.44	9.60
-25 +45 mesh	0.354 mm	33.51	33.14	34.53
-45 +200 mesh	0.074 mm	26.54	30.12	31.49
-200 +325 mesh	0.044 mm	4.92	6.61	9.57
-325 +400 mesh	0.037 mm	1.44	1.72	3.43
-400 mesh	<0.037 mm	8.09	8.23	9.56
		100.00	100.00	100.00

Elemental Analysis (%)

Sample Label	S_{Total}	Ca_{Total}	$Ca_{as\ CaO}$	Ignition Loss 450°C	Ignition Loss 1050°C
Original	11.94	29.95	41.93	<0.1	3.79
Cold Drip	10.89	30.16	42.23	4.70	9.12
Hot Water	10.66	28.41	39.78	5.84	10.80

Carbon and hydrogen were determined by CHN analyzer.

	$\%\ C_{Total}$	$\%\ CO_{2\ calc}$	$\%\ H_{Total}$	$\%\ H_2O_{calc.}$
Original	1.38	5.06	--	--
Cold Drip	1.41	5.17	0.62	5.58
Hot Water	1.36	4.99	0.81	7.29

rpc

Re-calculation yields the following results:

	% Ca_{Total}	% CaO	*% $Ca(OH)_2$	*% $CaCO_3$	% $CaSO_{4calc.}$
Original	29.95	23.38	<0.1	11.50	29.41
Cold Drip	30.16	5.02	22.94	11.75	28.17
Hot Water	28.41	<0.1	29.97	11.34	26.09

*Calculated from C and H results above.

I. J. I. Delaney

Dr. I. J. I. Delaney
Manager, Analytical Services

Dr. C. D. Desjardins
Head, Process Chemistry Department

/mb

rpc

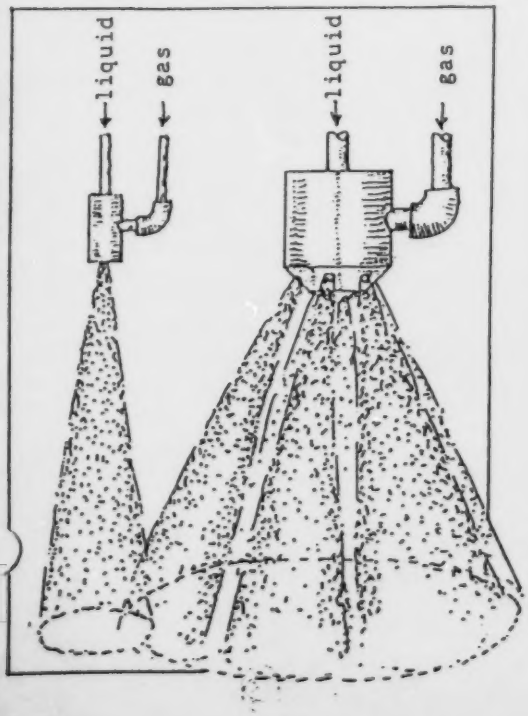
APPENDIX D

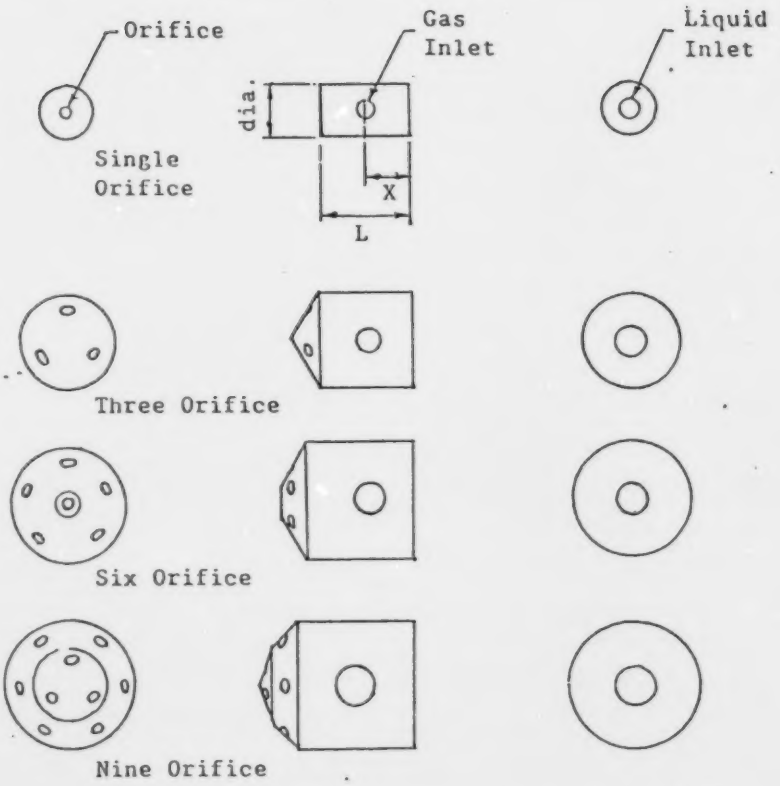
Spray Nozzle Specification

The Turbotak-Caldyn Nozzle

Turbotak nozzles finely atomize water, high viscosity liquids, and slurries by means of compressed air. Droplet sizes are controlled from 5 to 200 μm by adjusting gas and liquid flows, and operating pressure.

Single orifice nozzles produce a full cone spray with a 15 degree total spray angle. The multiple orifice nozzle provides larger flow capacities and wider spray angles. Each orifice performs as an independent single orifice nozzle. Their combination approximates a full cone spray pattern (or other spray pattern if desired) with design total spray angles from 25 to 120 degrees.





STANDARD DIMENSIONS AND CONNECTION SIZES

Nozzle	dia. (mm)	X (mm)	L (mm)	Connections (NPT) gas	liquid
Single Orifice					
1 to 4mm	25	26	40	1/8"	1/4"
5 to 8mm	35	30	50	1/4"	3/8"
9 to 12mm	40	37	65	3/8"	1/2"
Three Orifice					
1 to 8mm	64	29	64	1/2"	3/4"
Six Orifice					
1 to 8mm	76	29	80	3/4"	3/4"
Nine Orifice					
1 to 8mm	100	40	100	1"	1"

Turbotak Nozzle Technical Information

Turbotak Nozzle Operation

The Turbotak nozzles utilize compressed air to atomize the liquid.* The gas impinges co-axially with the liquid and generates an intense sound field into which the mixture is directed, supplying energy for breakup. The Turbotak design exploits the property that sonic velocity of a two-phase mixture is significantly lower than that of air or water alone, for quiet, efficient operation. The spray produced is enveloped with air as it leaves the orifice resulting in reduced erosion and long nozzle life.

Simple in design, the nozzles are thought to be the most efficient currently on the market. Sizes range from 1.0 mm to 35 mm orifice diameter so that in most cases, plugging is unlikely, an item of concern with most competitive nozzles. They are available in a wide variety of materials from stainless steels, aluminum, brass and various plastics including Teflon, Kynar, PVC etc. Single orifice nozzles produce a full cone spray of approximately 15°. Wider spray angles are obtained by using multiple orifice nozzles.

Turbotak nozzles are ideal for hot gas stream quenching or cooling, for improving the performance of existing nozzles, for complete combustion of oil, sulfur and a variety of other combustible liquids, for making snow, for submerged combustion, for pre-scrubbing dirty gases, for

* High pressure steam can be used instead of air. In this case, the water must be preheated to near its saturation temperature (i.e., at least to 180°F) in order to achieve a two-phase mixture and proper atomization.

adsorption and absorption. They can readily produce droplets ranging from 5 μm to over 100 μm in size to meet a wide variety of requirements. Figure 1 illustrates the characteristic curves for a Turbotak 2 mm nozzle. The approximate Sauter droplet diameters have been super-imposed on this figure. Also shown are the number mean curves of d = 100 μm, 50 μm, and 30 μm.

Sizing Nozzles

Figure 1 can be used for any size of Turbotak nozzle by simply multiplying the air and water flows by the ratio of the squares of the orifice diameters of the nozzles (flow is proportional to total exiting cross sectional area). For example, if you require 10 μm (Sauter) droplets, a 2 mm nozzle would have a capacity of 10 kg/hr at 60 psig. Your requirements might be 5 USgpm (1132 kg/h). The following ratio holds:

$$\frac{10 \text{ kg/h}}{2^2} = \frac{1132 \text{ kg/h}}{x^2} \; ; \qquad x = 21.3 \text{ mm}$$

In this size range, nozzles available are either 20 mm or 25 mm and one would have to re-examine their original requirements to determine which nozzle is best.

For the same flow, four nozzles may be preferred with the total flow divided equally to each nozzle. In this case, four 10 mm nozzles would be used. Similarily, for a nozzle containing 3 discharge orifices, the calculation is transformed as follows:

$$\frac{10 \text{ kg/h}}{2^2} = \frac{1132 \text{ kg/h}}{3\,x^2} \; ; \qquad x = 12.3 \text{ mm}$$

Nozzle Flexibility

An advantage of Turbotak nozzles is their ability to produce almost any desired droplet size (5–100 μm) by simply varying air and water flows (and pressure). It can therefore be tuned for optimal conditioning of most gas stream conditions. For coarse particulate removal, evaporative cooling, et cetera the nozzle may be operated in a "low-energy" mode (20–40 psig) to produce water droplets with a number-mean-diameter in the 30–50 micron range. For more intensive conditioning processes, the nozzle may be operated in a "higher energy" mode by increasing the air pressure to the nozzle while maintaining constant water flow. This produces smaller water droplets with diameters in the 5 – 20 micron range and normally requires pressures of about 60 psig.

Droplet Size Distribution

The spray generated by any nozzle is not homogenous but composed of droplets of various sizes. For Turbotak nozzles, droplet sizes range from about 0 to 500 μm in the spray. Typical droplet size distributions for three spray conditions are shown in Figure 2. These distributions are usually represented by an average droplet size, commonly referred to as the Sauter mean and number mean diameters of the distribution, defined below (ref: Perry's Handbook of Chemical Engineering):

Sauter mean diameter (d_{32}): The diameter of a droplet that has the same ratio of surface area to mass as the total drop population.

Number mean diameter (d_{50}): The diameter of a droplet that is larger than exactly half of the total number of droplets in the population.

The discrepancy between the number mean and Sauter droplet diameters relates to the droplet size distribution, especially for larger mean droplet sizes. A correlating broad size distribution is represented by an exceptionally large Sauter diameter due to the effects of the larger droplets in the population. When smaller droplets are produced, larger droplets are eliminated and the Sauter diameter and number mean diameter are similar.

Controls

Water pressure to the nozzle should be close to the air pressure to prevent backflow of air into the water line. Water flow is controlled and monitored by a flow meter and valve system. Figure 3 shows a schematic of the minimum controls required for proper operation of the nozzle. These should be located as close as feasible to the nozzle to ensure accurate control.

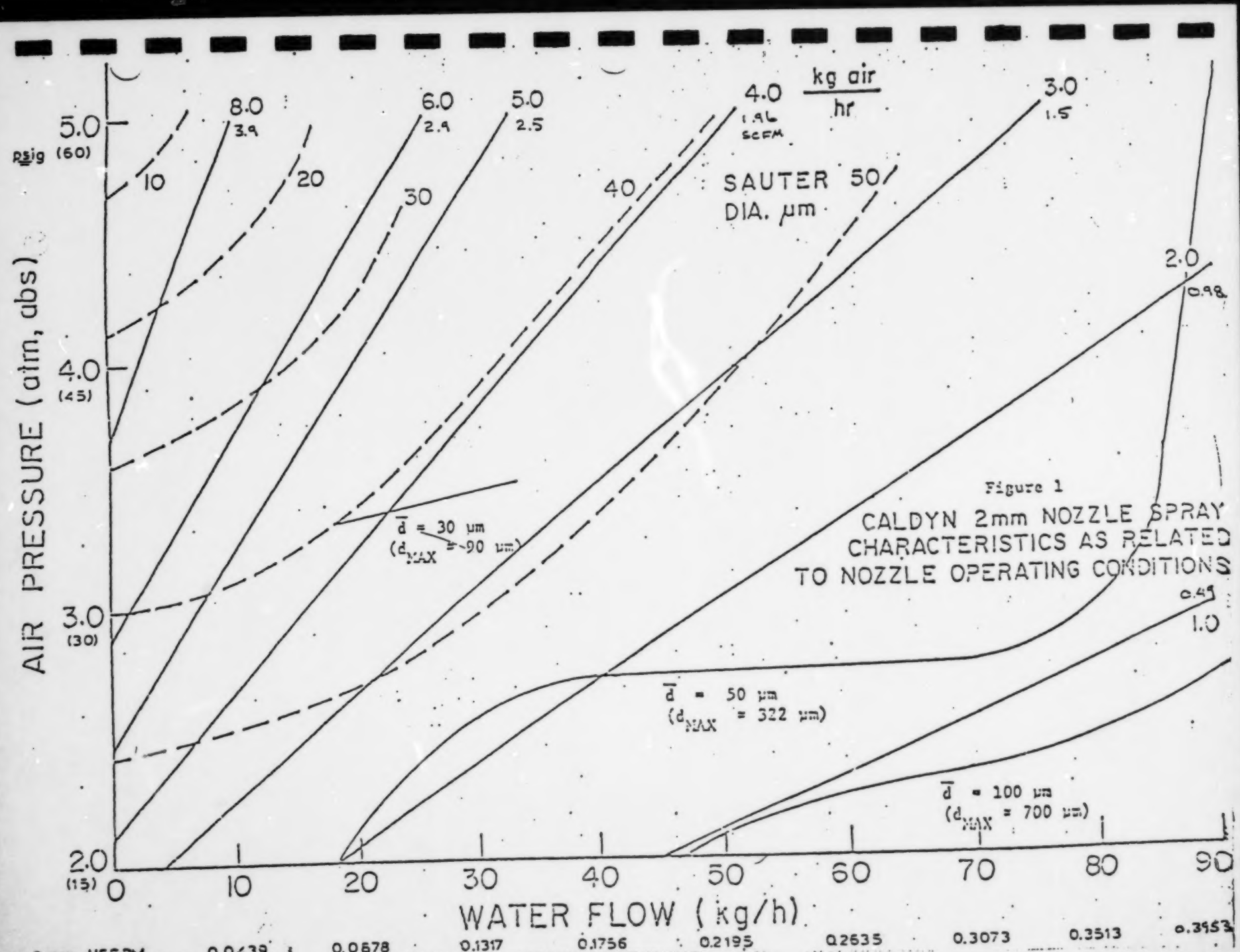


Figure 1

CALDYN 2mm NOZZLE SPRAY CHARACTERISTICS AS RELATED TO NOZZLE OPERATING CONDITIONS

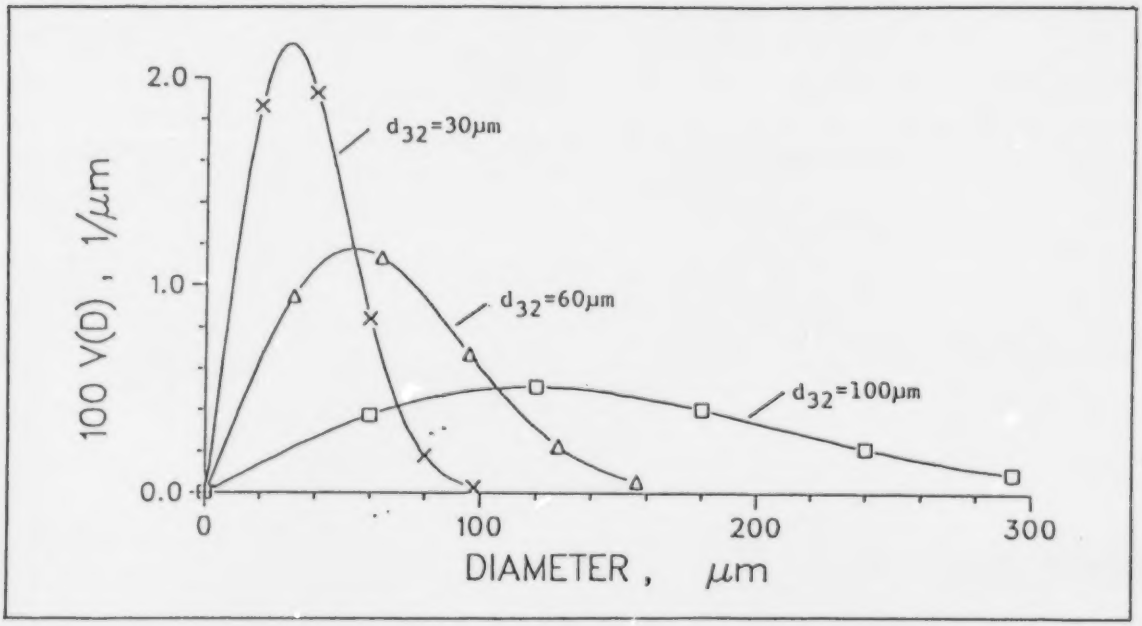
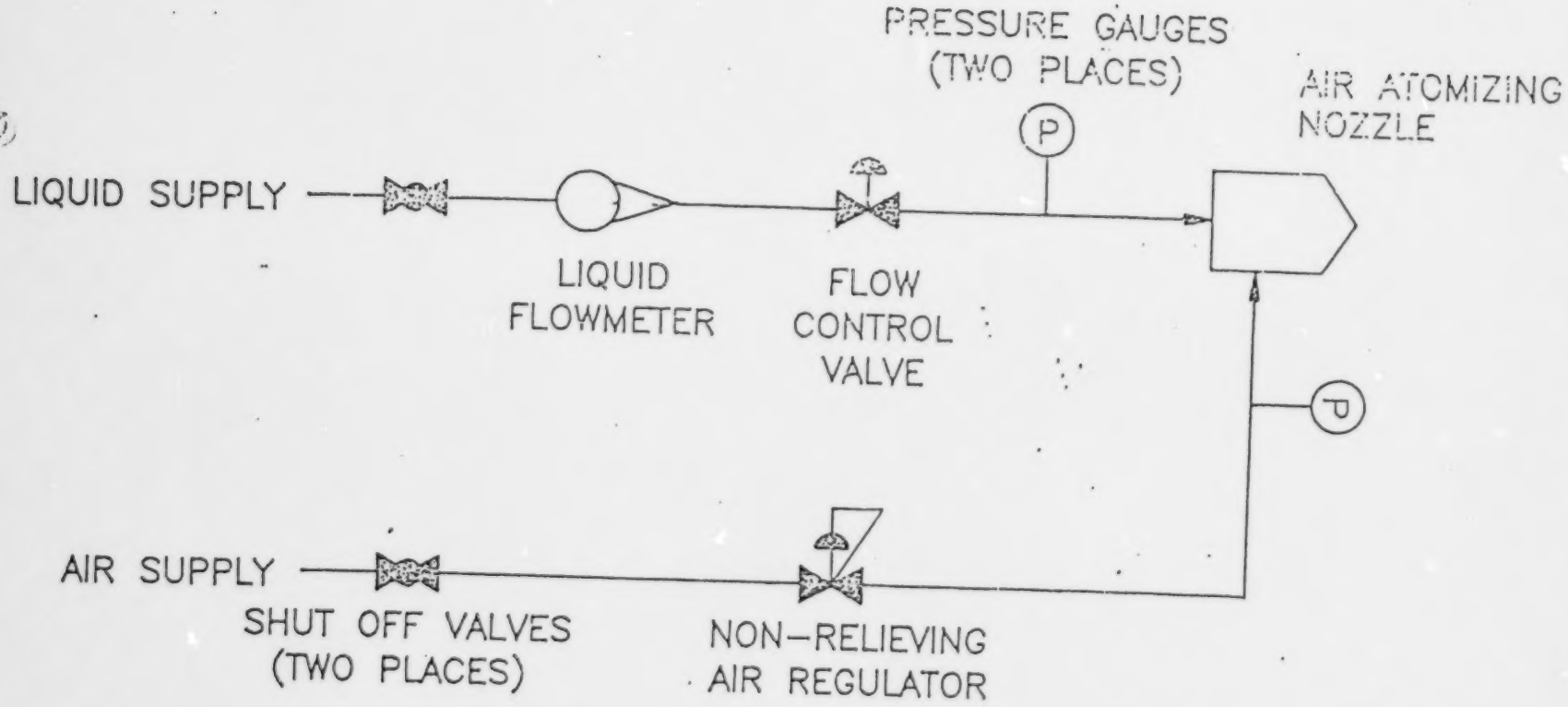


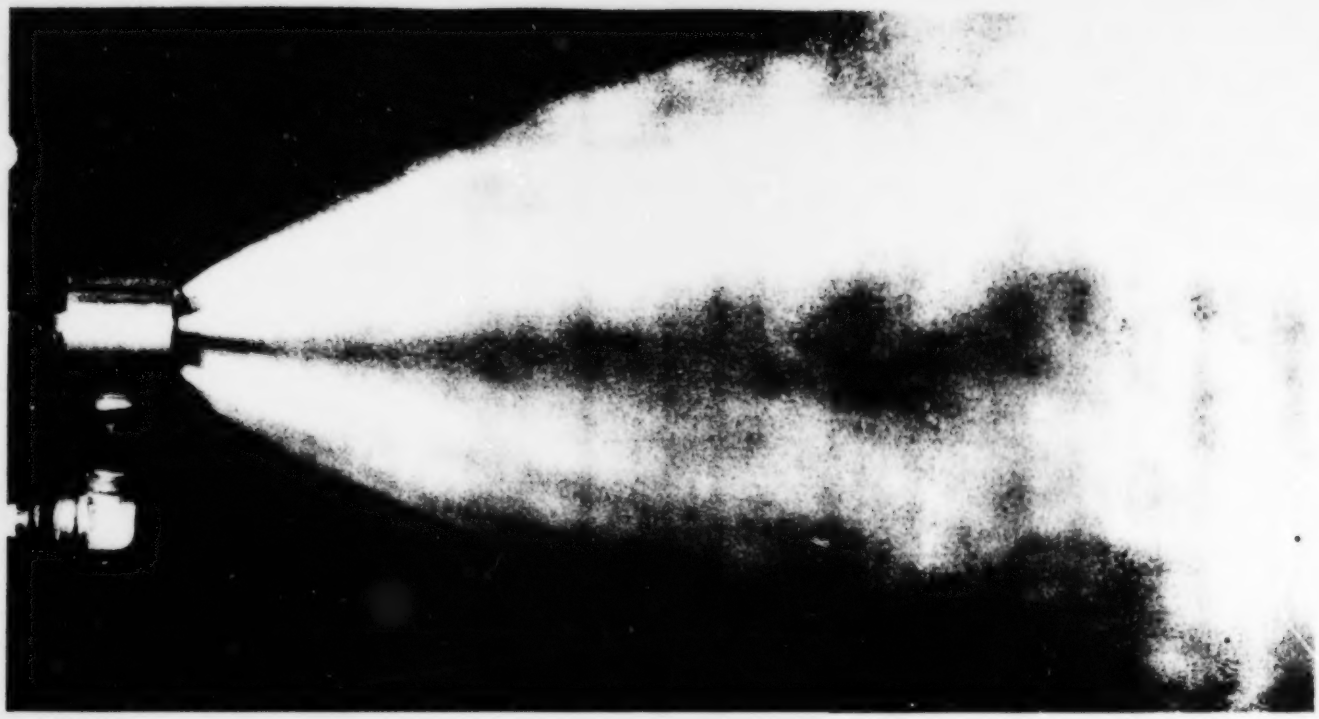
Figure 2: Droplet size distribution for Sauter Mean Diameter (d_{32}) equal to 30 μm, 60 μm and 100 μm.



TURBOTAK INC

TYPICAL CONTROL CIRCUIT FOR TURBOTAK NOZZLES

Figure 3 : Typical Control Circuit for Nozzles



TURBOTAK ATOMIZING NOZZLES

PROVEN EFFICIENCY

Turbotak atomizing nozzles are based on two phase flow principles. Simple and rugged in design, this is the ideal nozzle for atomizing virtually any liquid or slurry that can be pumped. Flows of 100+ US gpm can be atomized through a single nozzle.

LOW ENERGY REQUIREMENTS

Comparative tests with a popular brand of sonic nozzle, indicated that the Turbotak nozzles required only half of the energy to produce 40 μm droplets. Droplet sizes from 5-50+ μm can be obtained by simple control of the air pressure to the nozzle. Over 7×10^{11} droplets can be produced from a single gallon of water with a surface area of up to 50,000 ft.^{2}

NON RESTRICTIVE PASSAGE

Large non-restrictive orifice diameters (1mm-35mm) make it possible to spray liquids and slurries containing over 40% solids. Under normal circumstances, erosion is virtually non-existent. Turbotak nozzles are available in any material that can be machined or moulded.

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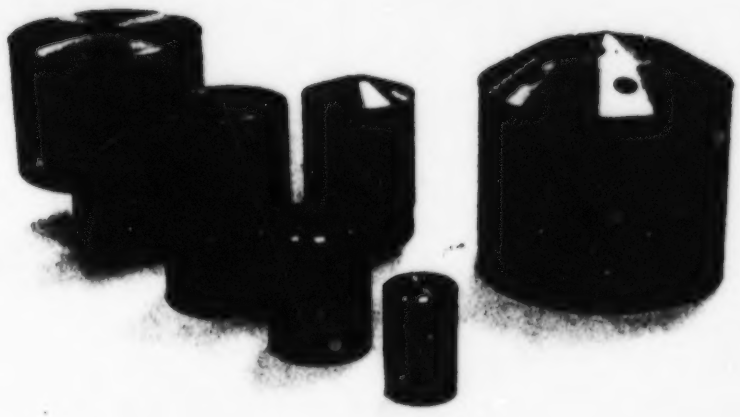

TYPICAL APPLICATIONS

Treatment of Gas Streams

- evaporative cooling
- peak temperature shaving
- hot gas stream quenching
- dust suppression
- humidification & conditioning
- scrubbing

Spraying Fluids

- waste incineration
- combustion
- fluid atomization
- snowmaking

Introduction of Finely Dispersed Gas to Fluids

- carbonization
- aeration
- flotation cells
- aerobic digestors

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